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TABLES AND CURVES FOR SOLUTION OF PROPELLER PROBLEMS BY THE DYSON METHOD, AND A NEW METHOD OF ESTIMATING REVOLUTIONS.

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The tables and curves referred to in this paper give a quick method of solving propeller problems, using the data given in Dyson's charts. The form of the equations for horsepower and speed given in his "Mystery of the Screw Propeller" has been modified to reduce the number of variables and thus make it possible to prepare the tables. The equation for indicated horsepower as given is

$$\text{I.H.P.} = \frac{D^2 \times IT_D \times P \times R}{291.8},$$

$$\text{But } R = \frac{TS}{\pi D},$$

$$\text{so we have } \text{I.H.P.} = \frac{(P \times D) \times IT_D \times TS}{291.8 \times \pi}$$

Both IT_D and TS are functions of the projected area ratio, so this equation may be expressed in the form

$$\text{I.H.P} = \frac{(\text{P} \times \text{D}) \times f\left(\frac{\text{P.A.}}{\text{D.A.}}\right)}{291.8 \times \pi}.$$

Treating the factor (P × D) as one quantity, all values of I.H.P. can be given for various values of $\frac{\text{P.A.}}{\text{D.A.}}$ and (P × D), and this method has been used for constructing one set of tables. In the same table is given the value of the effective horsepower.

Since E.H.P. = P.C. × I.H.P., this value can also be tabulated for various values of (P × D) and $\frac{\text{P.A.}}{\text{D.A.}}$, as P.C. is also a function of $\frac{\text{P.A.}}{\text{D.A.}}$.

The equation for the speed is given as

$$\text{V} = \frac{\text{P} \times \text{R} \times (1 - \text{S})}{101.33}.$$

$$\text{But R} = \frac{\text{TS}}{\pi \text{D}},$$

$$\text{therefore V} = \frac{\text{P}}{\text{D}} \times \frac{\text{TS} \times (1 - \text{S})}{\pi \times 101.33}.$$

Here $\frac{\text{P}}{\text{D}}$ is treated as one quantity, and this leaves two variables—the projected area ratio and the slip block coefficient. The equation may be expressed in the form

$$\text{V} = \frac{\text{P}}{\text{D}} \times \frac{f\left(\frac{\text{P.A.}}{\text{D.A.}}\right) \times f(\text{SBC})}{\pi \times 101.33}.$$

Speeds are tabulated for each value of $\frac{\text{P.A.}}{\text{D.A.}}$ on various $\frac{\text{P}}{\text{D}}$ ratios and various slip block coefficients.

The form of the equations for the revolutions has not been changed; it is $R = \frac{TS}{\pi D}$.

The tables for revolutions, speed and horsepower are so arranged as to facilitate interpolation.

The curves given are self-explanatory and are merely time-savers; the values of x to be used in curve 1 for obtaining values of $\left(\frac{e.h.p.}{E.H.P.}\right)^x$ and $\left(\frac{v}{V}\right)^x$ are to be obtained from sheets E and E_2 of Dyson's charts. The values of I.H.P.$_d$ given in curve 2 have been plotted by using the values of Z given on sheet D of Dyson's charts.

The final form of the equations used are then,

$$(1) \quad \ldots \quad \text{I.H.P.} = \frac{(P \times D) \times f\left(\frac{P.A.}{D.A.}\right)}{291.8 \times \pi} \quad \ldots \quad \text{(Table 2)}$$

$$(2) \quad \ldots \quad \text{E.H.P.} = \frac{(P \times D) \times f\left(\frac{P.A.}{D.A.}\right)}{291.8 \times \pi} \quad \ldots \quad \text{(Table 2)}$$

$$(3) \quad \ldots \quad V = \left(\frac{P}{D}\right) \times \frac{f\left(\frac{P.A.}{D.A.}\right) \times f(SBC)}{\pi \times 101.33} \quad \ldots \quad \text{(Table 3)}$$

$$(4) \quad \ldots \quad R = \frac{TS}{\pi D} \quad \ldots \quad \text{(Table 1)}$$

The tables and curves as given are intended to be used in the solution of two forms which will cover practically all cases of propeller design.

The following data will be known or will be assumed.

(1) The designed speed of the ship v; (2) the designed revolutions of the engines, R_d; (3) the hull plans from which can be obtained the slip block coefficient, SBC, and (4) the effective horsepower required at the designed point, *e.h.p.* From the body lines the maximum diameter that can be used to give the proper tip clearance according to sheet C, Dyson's charts, can be obtained. The data at hand for the propeller design will then be v, R_d, *e.h.p.*, and D.

As the tables and curves are merely a graphic method of solving the forms, these forms will be given first to make the method clearer. The first form is used to obtain the pitch. The first problem given is that of a battleship.

Given—

L.W.L (length on load water line) = 600 feet.
B (beam) = 97.375 feet.
D′ (draught) = 30 feet.
D.S. (displacement) = 32,000 tons.
v (designed speed) = 21 knots.
R_d (designed revolutions) = 175.

$$\frac{B}{L.W.L.} = .1623.$$

$$\text{N.B.C. (nominal block coeff.)} = \frac{D.S. \times 35}{L.W.L. \times B \times D'} = .639.$$

St. B.C. (standard block coefficient) = .615 (obtained from sheet A, Dyson's charts).

C $\mathfrak{M}$ = (coefficient of fineness of midship section) = .98.

$$\text{S.B.C. (slip block coefficient)} = \frac{\text{St. B.C.} \times \text{St. C } \mathfrak{M}}{\text{Actual C } \mathfrak{M}} = .615.$$

e.h.p. (bare hull) = 16,600.

Appendage resistance = 13.55 per cent. (sheet B).

e.h.p. (total) = 16,600 × 1.1355 = 18,850.

e.h.p. (1 shaft) = 4,712.5.

D (maximum allowed diameter) = 13 feet.

Next assume a value of $\frac{e.h.p.}{E.H.P.}$, which will be about right for the type of ship. This will be about .8 or .9 for battleships, battle cruisers, scouts and destroyers; for low-powered vessels it will be smaller. It is not essential that this load fraction be even approximately correct, but it will make errors of interpolation and plotting have less effect if it is correct within .2. If the value of $\frac{e.h.p.}{E.H.P.}$ is entirely unknown, use .9 for

this fraction. Using a value of $\frac{e.h.p.}{E.H.P.} = .8$ solve for the pitch, using form 1 as follows:

$$\frac{e.h.p.}{E.H.P.} = .8.$$

$\frac{P.A.}{D.A.}$ (assumed)	.37	.39	.41
E.H.P. $= \frac{e.h.p. \text{ (1 shaft)}}{\frac{e.h.p.}{E.H.P.}}$	5,890	5,890	5,890
P.C. (sheet D, Dyson's charts)	.639	.626	.613
I.H.P. $= \frac{E.H.P.}{P.C.}$	9,220	9,410	9,610
$I.T._D$ (sheet D, Dyson's charts)	5.3	5.78	6.27
D (maximum allowed)	13	13	13
D^2	169	169	169
$P \times R = \frac{I.H.P. \times 291.8}{II_D \times D^2}$	3,004	2,811	2,648
1 − S (sheet D, Dyson's charts)	.894	.891	.889
$V = \frac{(P \times R) \times (1 - S)}{101.33}$	26.5	24.71	23.23
v (designed speed)	21	21	21
$\frac{v}{V}$	.7925	.849	.904
$\pi D =$	40.85	40.85	40.85
T.S. (sheet D, Dyson's charts)	8,010	8,400	8,750
$P \times R =$	3,004	2,811	2,648
$P = \frac{\pi D \times (P \times R)}{T.S.}$	15.32	13.67	12.36
$R = \frac{T.S.}{\pi D}$	196	205.6	214.2
$\sqrt{K}$ (sheet C, Dyson's charts)	1	1	1
x (sheet E_2, Dyson's charts)	.96	.73	.5
$\left(\frac{e.h.p.}{E.H.P.}\right)^x$	.807	.85	.895
$R_d = R \times \sqrt{K} \times \left(\frac{e.h.p.}{E.H.P.}\right)^x$	158.2	174.7	191.6

Plot the values of P and R_d against $\frac{P.A.}{D.A.}$. With given value of R_d pick out $\frac{P.A.}{D.A.}$ and then P. This will be the pitch necessary to give the desired revolutions at the designed speed. These values are plotted in Fig. 1, from which we get the value of P to be 13.61 feet.

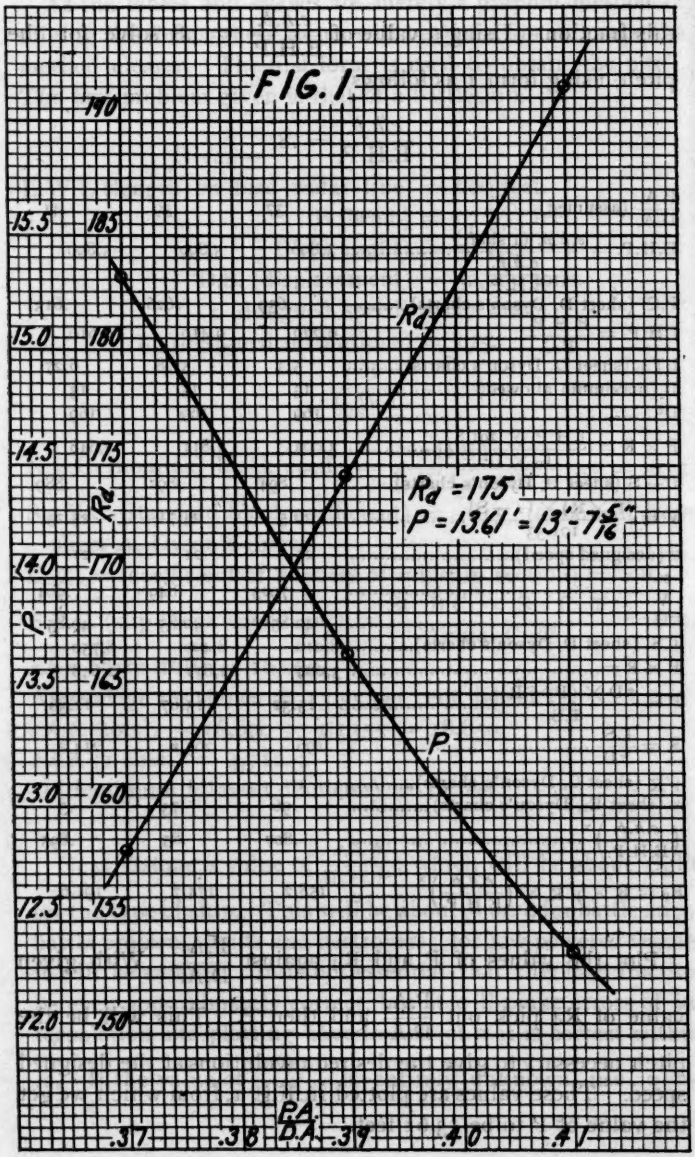


FIG. 1
190
15.5
185
15.0
180
14.5
175
Rd
14.0
170
Q
13.5
165
13.0
160
12.5
155
12.0
150
Rd
P
Rd = 175
P = 13.61' = 13'-7 5/16"
.37
.38
P.A.
D.A.
.39
.40
.41

Having the pitch and diameter of the propeller, we can now complete the design to find the most efficient propeller having these values. Proceed as follows (form 2).

$\frac{\text{P.A.}}{\text{D.A.}}$ (assumed)	.35	.37	.39	.41	.43
D (assumed)	13	13	13	13	13
πD	40.85	40.85	40.85	40.85	40.85
T.S. (sheet D, Dyson's charts)	7,630	8,010	8,400	8,750	9,125
$R = \frac{\text{T.S.}}{\pi D}$	186.6	196	205.6	214.2	223.4
P (from form 1)	13.61	13.61	13.61	13.61	13.61
P × R	2,540	2,668	2,799	2,915	3,042
D^2	169	169	169	169	169
$I.T_D$ (sheet D, Dyson's charts)	4.8	5.3	5.78	6.27	6.77
$\text{I.H.P.} = \frac{(P \times R) \times D^2 \times \text{I.T.}_D}{291.8}$	7,060	8,190	9,370	10,580	11,930
P.C. (sheet D, Dyson's charts)	.652	.639	.626	.613	.6
E.H.P. = I.H.P. × P.C.	4,602	5,230	5,870	6,486	7,160
e.h.p. (*e.h.p.* curve)	4,712.5	4,712.5	4,712.5	4,712.5	4,712.5
$\frac{e.h.p.}{\text{E.H.P.}}$	1.024	.901	.8025	.7265	.658
1 − S (sheet D, Dyson's charts)	.897	.894	.891	.889	.885
P × R	2,540	2,668	2,799	2,915	3,042
$V = \frac{(P \times R) \times (1 - S)}{101.33}$	22.5	23.55	24.6	25.56	26.55
v = (designed speed)	21	21	21	21	21
$\frac{v}{V}$	.933	.8915	.854	.8215	.793
x $\left(\text{for } \frac{v}{V} \text{ and } \frac{e.h.p.}{\text{E.H.P.}}\right)$ (sheet E_2, Dyson's charts)	2.695	1.087	.733	.632	.582
$\left(\frac{e.h.p.}{\text{E.H.P.}}\right)^x$	.936	.891	.851	.816	.783
$\sqrt{K}$ (sheet C, Dyson's charts)	1	1	1	1	1
R	187	196.3	205.8	214.4	223.6
$R_d = R \times \sqrt{K} \times \left(\frac{e.h.p.}{\text{E.H.P.}}\right)^x$	175	175	175	175	175
I.H.P. (total) = I.H.P. × No. shafts	28,240	32,760	37,480	42,320	47,720
S.H.P. (total) = I.H.P. (total) × .92	25,990	30,140	34,400	38,930	43,900
10^x (sheet D, Dyson's charts)	.98	1.125	1.29	1.42	1.57
K (sheet C, Dyson's charts)	1	1	1	1	1
$\text{S.H.P.}_d = \frac{\text{S.H.P.} \times K}{10^x}$	26,530	26,800	26,780	27,400	27,980

It is unnecessary to work out $\left(\frac{e.h.p.}{\text{E.H.P.}}\right)^x$ and R_d, as this will give the same result, 175 r.p.m., in each case, but the work serves as a check. Plot the values obtained from this form with values of $\frac{\text{P.A.}}{\text{D.A.}}$ as abscissae. These are given in Fig. 2. In this figure it is seen that the most efficient screw within

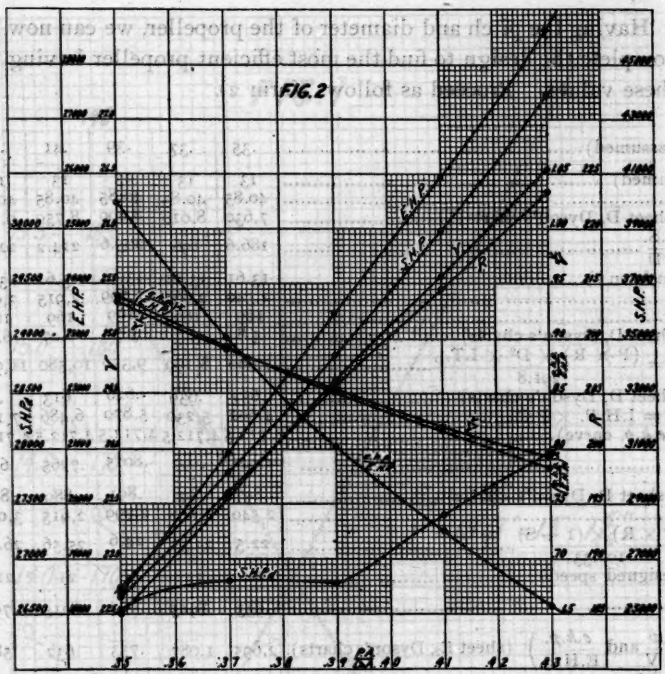


FIG. 2
E.H.P.
S.H.P.
S.H.P.
E.H.P.
S.H.P.
E.H.P.
S.H.P.
E

To do this same work using the tables and curves a similar procedure would be followed. The same general data would be given.

L.W.L. = 600 feet	$\frac{B}{L.W.L.} = .1623$
B = 97.375 feet	N.B.C. = .639
D′ = 30 feet	St.B.C. = .615
D.S. = 32,000 tons	C. $\mathfrak{D}$ = .98
v = 21 knots	S.B.C. = .615
R_d = 175	*e.h.p.* (bare hull) 16,600.

Appendage resistance = 13.55 per cent.
e.h.p. (total) = 18,850
e.h.p. (1 shaft) = 4,712.5
D = 13 feet

As before, the first step will be to find the pitch.

Assume a value of $\frac{e.h.p.}{E.H.P.} = .8$

Then E.H.P. $= \frac{4,712.5}{.8} = 5,890.$

Assume three or more values of $\frac{P.A.}{D.A.}$ and pick out values as follows from Tables 1, 2 and 3.

$\frac{P.A.}{D.A.}$ (assumed)	.37	.39	.41
$\frac{e.h.p.}{E.H.P.}$ (assumed)	.8	.8	.8
E.H.P.	5,890	5,890	5,890
P × D (Table 2)	199.5	176.9	160.5
D (assumed)	13	13	13
$P = \frac{P \times D}{D}$	15.34	13.62	12.35
$\frac{P}{D}$	1.1815	1.05	.95
S.B.C.	.615	.615	.615
V (Table 3)	26.6	24.71	23.27
v (designed speed)	21	21	21
$\frac{v}{V}$	.789	.85	.9025
x (sheet E_2, Dyson's charts)	.97	.73	.51
$\left(\frac{e.h.p.}{E.H.P.}\right)^x$ (curve 1)	.805	.85	.893
$\sqrt{K}$ (sheet C, Dyson's chart's)	1	1	1
R (Table 1)	196.3	205.8	214.4
R_d (curve 3)	158	174.8	191.5

TABLE I-R.

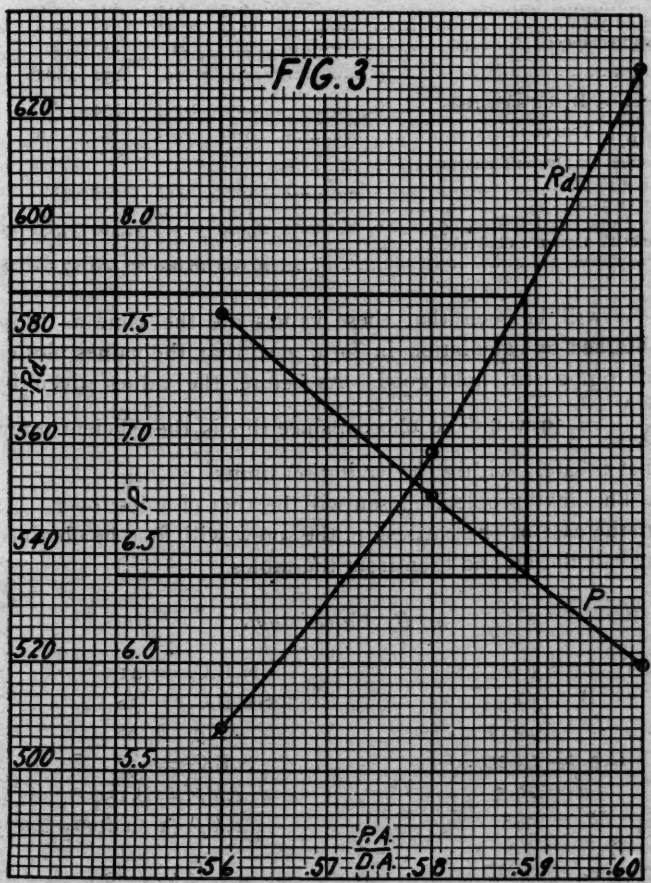
D

PA/DA	9°	12°	15°	18°	21°	2.0'	2.5'	3.0'	3.5'	4.0'	4.5'	5.0'	5.5'	6.0'	6.5'	7.0'	7.5'	8.0'	8.5'	9.0'	9.5'	10.0'	10.5'	11.0'	11.5'	12.0'	12.5'	13.0'	13.5'	14.0'	14.5'	15.0'	15.5'	16.0'	16.5'	17.0'	17.5'	18.0'	18.5'	19.0'	19.5'	20.0'	PA/DA
.25	2120	1591	1273	1061	909	795	636	531	455	398	354	318	290	265	245	228	212	199	187	177	168	159	152	145	138	133	127	122	118	114	110	106	103	100	97	94	91	88	86	84	82	80	.25
.24	2230	1671	1337	1114	955	835	668	557	477	418	371	334	304	279	257	239	223	209	197	186	176	167	159	152	145	139	134	129	124	119	115	111	108	105	101	98	96	93	90	88	86	84	.24
.25	2335	1750	1400	1167	1000	875	700	583	500	438	389	350	318	292	270	250	233	219	206	194	184	175	167	159	151	146	140	135	130	125	121	117	113	109	106	103	100	97	95	92	90	88	.25
.26	2444	1833	1466	1222	1047	916	733	611	524	458	407	366	334	306	282	262	245	229	216	204	195	183	175	167	160	153	147	141	136	131	126	122	118	115	111	108	105	102	99	97	94	92	.26
.27	2548	1910	1528	1273	1091	954	764	637	546	478	424	382	348	319	294	273	255	239	224	213	201	191	182	174	166	159	153	147	142	136	132	127	123	120	116	112	109	106	103	101	98	95	.27
.28	2645	1982	1586	1322	1133	996	793	661	567	496	441	397	361	331	305	284	265	248	233	221	209	198	189	180	173	166	159	153	147	142	137	132	128	124	120	117	113	110	107	105	102	100	.28
.29	2737	2052	1642	1369	1173	1026	821	681	586	513	456	410	374	343	316	294	274	257	241	228	216	205	196	187	179	171	165	158	152	147	141	137	132	128	125	121	117	114	111	108	105	103	.29
.30	2822	2117	1694	1412	1210	1057	846	706	605	529	470	423	385	353	326	303	283	265	249	236	223	212	202	192	184	176	170	163	157	151	146	141	136	132	129	124	121	118	114	112	109	106	.30
.31	2900	2174	1740	1450	1242	1086	870	725	621	544	483	435	396	363	335	311	290	272	256	242	229	217	207	198	189	181	174	167	161	155	150	145	140	136	132	128	124	121	118	115	111	109	.31
.32	2993	2244	1795	1497	1282	1121	897	748	641	561	499	449	408	375	346	321	300	281	264	250	236	224	214	204	195	187	180	173	166	160	155	150	145	140	136	132	128	125	121	119	115	112	.32
.33	3077	2308	1846	1539	1319	1153	923	769	659	577	513	461	420	385	355	330	308	287	271	257	243	231	220	210	201	192	185	178	171	165	159	154	149	144	140	136	132	128	125	122	118	115	.33
.34	3162	2372	1898	1582	1355	1185	949	791	677	593	527	474	431	396	365	339	317	297	279	264	250	237	226	215	207	198	190	183	176	169	163	158	153	148	144	139	136	132	128	125	122	119	.34
.35	3238	2429	1943	1620	1388	1213	971	810	694	607	539	485	442	405	374	347	324	304	286	270	256	243	231	221	211	202	195	187	180	173	167	162	157	152	147	143	139	135	131	128	124	121	.35
.36	3310	2483	1986	1655	1419	1240	993	828	709	621	551	496	452	414	382	355	332	311	292	276	261	248	236	226	216	207	199	191	184	177	171	166	160	155	151	146	142	138	134	131	127	124	.36
.37	3400	2550	2039	1700	1457	1274	1020	850	728	638	568	509	464	425	393	365	341	319	300	284	268	255	243	232	222	212	204	196	189	182	176	170	164	160	155	150	146	142	138	135	131	127	.37
.38	3485	2613	2090	1742	1493	1305	1045	871	746	653	580	522	475	436	402	374	349	327	307	291	275	261	249	237	227	218	209	202	194	186	180	174	168	163	159	154	149	145	141	138	134	131	.38
.39	3565	2674	2139	1782	1528	1336	1069	891	764	669	594	534	486	446	412	382	357	334	314	297	281	267	255	243	233	223	214	206	198	191	184	178	172	167	162	157	153	149	145	141	137	134	.39
.40	3639	2729	2185	1820	1560	1365	1092	910	780	683	606	546	497	455	420	390	364	341	321	304	287	273	260	248	238	227	218	210	202	195	188	182	176	171	166	160	156	152	148	144	140	136	.40
.41	3714	2785	2228	1857	1592	1391	1114	928	795	697	619	557	507	465	429	398	372	348	327	310	293	278	265	253	242	232	223	214	207	199	192	186	179	174	169	164	159	155	151	147	143	139	.41
.42	3798	2849	2279	1899	1628	1423	1139	950	814	712	633	570	518	475	439	407	380	356	335	317	300	285	271	259	248	237	228	219	211	203	197	190	184	178	173	167	163	158	154	150	146	142	.42
.43	3873	2904	2323	1936	1660	1451	1162	968	830	726	645	581	528	485	447	415	387	363	341	323	306	290	277	264	253	242	233	224	215	207	201	194	187	182	176	171	166	162	157	153	149	145	.43
.44	3955	2967	2373	1978	1695	1482	1186	989	847	742	659	594	540	495	457	424	395	371	349	330	312	296	282	269	258	247	238	228	220	212	205	198	191	186	180	174	170	165	160	157	152	148	.44
.45	4036	3027	2421	2018	1730	1512	1211	1009	864	757	672	606	551	505	466	433	403	379	356	337	319	302	288	275	263	252	243	233	224	216	209	202	195	189	184	178	173	168	164	160	155	151	.45
.46	4117	3088	2470	2059	1764	1542	1235	1029	882	772	686	618	562	515	475	441	411	386	363	343	325	309	294	280	268	257	247	238	229	220	213	206	199	193	187	181	177	172	167	163	158	154	.46
.47	4193	3145	2515	2097	1797	1571	1258	1048	898	786	699	629	572	525	484	450	419	393	370	350	331	314	299	286	274	262	252	242	233	224	217	210	203	197	191	185	180	175	170	166	161	157	.47
.48	4278	3208	2566	2139	1834	1603	1283	1069	916	802	713	642	584	535	494	459	427	401	377	357	338	321	305	291	279	267	257	247	238	229	222	214	207	201	195	189	183	178	174	169	164	160	.48
.49	4384	3288	2630	2192	1879	1642	1315	1096	939	822	730	658	598	549	506	470	438	411	386	366	346	329	313	299	286	274	263	253	244	235	227	219	212	206	199	193	188	183	178	174	168	164	.49
.50	4477	3358	2686	2239	1919	1677	1343	1119	959	840	746	672	611	560	517	480	447	420	395	374	353	335	320	305	292	280	269	259	249	240	232	224	216	210	204	197	192	187	182	177	172	168	.50
.51	4575	3539	2745	2288	1961	1714	1372	1144	980	858	762	687	624	572	528	491	457	429	403	382	361	343	327	312	299	286	275	264	254	245	237	229	221	215	208	202	196	191	185	181	176	171	.51
.52	4675	3506	2804	2337	2004	1751	1402	1169	1001	877	779	702	638	585	540	501	467	438	412	390	369	350	334	318	305	292	281	270	260	250	242	234	226	219	213	206	201	195	190	185	180	175	.52
.53	4796	3597	2877	2398	2055	1797	1438	1199	1027	900	799	720	654	600	554	514	479	450	425	400	379	359	342	327	313	300	288	277	267	257	249	240	232	225	218	211	206	200	194	190	184	180	.53
.54	4915	3686	2948	2457	2106	1841	1474	1229	1053	922	819	738	671	614	567	527	491	461	435	410	388	368	351	335	321	307	295	284	273	265	255	246	237	230	224	217	211	205	199	195	189	184	.54
.55	5042	3781	3025	2521	2161	1889	1512	1260	1080	946	840	757	688	631	582	541	504	473	444	421	398	378	360	343	329	315	303	291	280	270	261	252	244	236	229	223	216	210	204	200	194	189	.55
.56	5169	3877	3101	2585	2216	1937	1551	1292	1107	970	861	776	705	647	597	554	516	485	456	431	408	387	369	352	337	323	311	298	287	277	268	258	250	242	235	228	222	216	210	205	199	194	.56
.57	5305	3979	3185	2653	2274	1988	1591	1326	1136	995	884	796	724	664	613	569	530	498	468	443	419	398	379	361	346	331	319	306	295	284	275	265	256	249	241	234	228	221	216	210	204	199	.57
.58	5462	4097	3277	2731	2341	2048	1638	1366	1170	1024	910	820	745	683	631	586	546	512	481	456	431	409	390	372	357	341	328	315	304	292	283	273	264	256	248	241	234	228	222	216	210	205	.58
.59	5611	4208	3366	2805	2405	2102	1683	1403	1202	1052	935	842	765	702	648	602	561	526	494	468	443	420	401	382	366	350	337	324	312	300	291	280	271	263	255	247	241	234	227	222	216	210	.59
.60	5783	4345	3475	2897	2483	2170	1738	1448	1241	1087	965	870	790	725	669	621	579	543	511	483	457	434	414	395	378	362	348	334	322	310	300	289	280	272	263	255	248	242	235	229	223	217	.60
.61	5959	4469	3575	2979	2554	2232	1787	1490	1276	1118	993	894	813	746	688	639	595	559	525	497	470	447	425	406	389	372	358	344	331	319	309	298	288	279	271	263	256	249	242	236	229	223	.61
.62	6133	4599	3679	3066	2628	2298	1839	1533	1314	1150	1022	921	837	767	708	658	613	575	540	512	484	460	438	418	400	385	369	354	341	328	318	306	296	288	279	270	265	256	249	243	236	230	.62

PA/DA 9° 12° 15° 18° 21° 2.0' 2.5' 3.0' 3.5' 4.0' 4.5' 5.0' 5.5' 6.0' 6.5' 7.0' 7.5' 8.0' 8.5' 9.0' 9.5' 10.0' 10.5' 11.0' 11.5' 12.0' 12.5' 13.0' 13.5' 14.0' 14.5' 15.0' 15.5' 16.0' 16.5' 17.0' 17.5' 18.0' 18.5' 19.0' 19.5' 20.0' PA/DA

It will be seen that the values of R_d and P are practically the same as those obtained by calculations in form 1, and consequently Fig. 1 holds good for these values from which we obtain P = 13.61 feet, as before.

The various propellers with D of 13 feet and P of 13.61 feet can now be found in a similar manner to the method of calculation already used in form 2. Proceed as follows:



$\frac{P.A.}{D.A.}$ (assumed)	.35	.37	.39	.41	.43
D (assumed)	13	13	13	13	13
P (work just completed)	13.61	13.61	13.61	13.61	13.61
P × D	176.9	176 9	176.9	176.9	176.9
I.H.P. (Table 2)	7,065	8,208	9,391	10,632	11,941
E.H.P. (Table 2)	4,608	5,219	5,890	6,492	7,147
e.h.p. (*e.h.p.* curve)	4,712.5	4,712 5	4,712.5	4,712.5	4,712.5
$\frac{e.h.p.}{E.H.P.}$	1.023	.903	.8	.726	.659
$\frac{P}{D}$	1.047	1.047	1.047	1.047	1.047
S.B.C.	.615	.615	.615	.615	.615
V (Table 3)	22.53	23.59	24.64	25.63	26.60
v (designed speed)	21	21	21	21	21
$\frac{v}{V}$	.932	.89	.852	.82	.7895
x (sheet E_2, Dyson's charts)	2.69	1.087	.734	.633	.583
$\left(\frac{e.h.p.}{E.H.P.}\right)^x$ (curve 1)	.9365	.8915	.85	.816	.783
$\sqrt{K}$ (sheet C, Dyson's charts)	1	1	1	1	1
R (Table 1)	187	196.3	205.8	214.4	223.6
R_d (curve 3)	175	175	175	175	175
S.H.P. (total) = I.H.P. × .92 × No. of shafts	26,000	30,200	34,580	39,150	43,950
K (sheet C, Dyson's charts)	1	1	1	1	1
$S.H.P._d$ (curve 2)	26,600	26,800	26,800	27,500	28,000

It will be seen that these values are the same as those obtained by calculation in form 2, so that the values plotted in Fig. 2 still hold good. As before, the values given by $\frac{P.A.}{D.A.} = .39$ would be chosen, since this is the efficient screw that is safely within the cavitation limits.

The next problem chosen will be that of a destroyer. As in the case of the battleship, the screw will first be obtained by calculation and then from the tables.

By Calculation.

L.W.L. = 300
B = 30.5
D′ = 9.417
D.S. = 1,020
v = 29.5
R_d = 588
$\frac{B}{L.W.L.} = .1017$

N.B.C. = .415
St. B.C. = .38
C 𝔐 = .684
S.B.C. = .38
e.h.p. = 8,150
e.h.p. (1 shaft) = 4,075
D = 7.25

M	H.P.	.5	1.0	5.0	10	20	30	40	50	60	70	80	90	100	110	120	130
.15	I.H.P.	6.5	13.09	65.45	131	262	393	524	655	785	916	1047	1178	1309	1440	1571	1701
	B.H.P.	4.6	9.26	46.25	93	185	278	370	463	555	648	740	833	926	1018	1110	1203
.16	I.H.P.	7.3	14.6	73	146	292	438	584	730	876	1022	1168	1314	1460	1606	1752	1898
	B.H.P.	5.1	10.29	51.45	103	206	309	412	5145	617	720	823	926	1029	1132	1235	1338
.17	I.H.P.	8.3	16.68	83.4	167	334	500	667	834	1001	1168	1334	1501	1668	1835	2002	2169
	B.H.P.	5.9	11.74	58.7	117	235	352	470	587	705	822	940	1057	1175	1292	1409	1527
.18	I.H.P.	9.4	18.84	94.2	188	377	565	754	942	1130	1319	1507	1696	1884	2072	2261	2449
	B.H.P.	6.5	13.05	65.2	131	261	392	522	653	783	914	1044	1175	1305	1436	1566	1697
.19	I.H.P.	10.4	20.84	104.2	208	417	625	834	1042	1250	1459	1667	1876	2084	2292	2501	2709
	B.H.P.	7.2	14.45	72.2	145	289	434	578	723	867	1012	1156	1301	1445	1590	1734	1879
.20	I.H.P.	11.4	22.8	114	228	456	684	912	1140	1368	1596	1824	2052	2280	2508	2736	2964
	B.H.P.	7.9	15.8	79	158	316	474	632	790	948	1106	1264	1422	1580	1738	1896	2054
.21	I.H.P.	12.4	24.8	124	248	496	744	992	1240	1488	1736	1984	2232	2480	2728	2976	3224
	B.H.P.	8.6	17.2	86	172	344	516	688	860	1032	1204	1376	1548	1720	1892	2064	2236
.22	I.H.P.	13.5	27.04	135.3	271	541	812	1082	1353	1624	1894	2165	2435	2706	2977	3247	3518
	B.H.P.	9.2	18.46	92.3	185	369	554	738	923	1108	1292	1477	1661	1846	2031	2215	2400
.23	I.H.P.	14.6	29.28	146.4	293	586	878	1171	4184	1757	2050	2342	2635	2928	3221	3514	3807
	B.H.P.	10.0	20.08	100.4	201	402	602	803	1004	1205	1406	1606	1807	2008	2209	2410	2611
.24	I.H.P.	16.0	31.90	159.5	319	638	957	1276	1595	1914	2233	2552	2871	3190	3509	3828	4147
	B.H.P.	10.8	21.6	108	216	432	648	864	1080	1296	1512	1728	1944	2160	2376	2592	2808
.25	I.H.P.	17.3	35.5	172.5	355	710	1065	1420	1775	2130	2485	2840	3195	3550	3905	4260	4615
	B.H.P.	11.5	23.0	115	230	460	690	920	1150	1380	1610	1840	2070	2300	2530	2760	2990
.26	I.H.P.	18.6	37.10	185.5	371	742	1113	1484	1855	2226	2597	2968	3339	3710	4081	4452	4823
	B.H.P.	12.3	24.55	122.8	246	491	737	982	1228	1473	1719	1964	2210	2455	2701	2946	3191
.27	I.H.P.	20.0	39.94	199.7	399	799	1198	1598	1997	2396	2796	3195	3595	3994	4393	4793	5192
	B.H.P.	13.0	26.05	130.3	261	521	782	1042	1303	1563	1824	2084	2345	2605	2866	3126	3387
.28	I.H.P.	21.6	43.2	216	432	864	1296	1728	2160	2592	3024	3456	3888	4320	4752	5184	5616
	B.H.P.	13.9	27.80	139	278	556	834	1112	1390	1668	1946	2224	2502	2780	3058	3336	3614
.29	I.H.P.	23.2	46.4	232	464	928	1392	1856	2320	2784	3248	3712	4176	4640	5104	5568	6032
	B.H.P.	14.8	29.5	147.5	295	590	885	1180	1475	1770	2065	2360	2655	2950	3245	3540	3835
.30	I.H.P.	24.9	49.8	249	498	996	1494	1992	2490	2988	3486	3984	4482	4980	5478	5976	6474
	B.H.P.	15.7	31.37	156.8	314	627	941	1255	1569	1882	2196	2510	2823	3137	3451	3764	4078
.31	I.H.P.	26.6	53.10	265.5	531	1062	1593	2124	2655	3186	3717	4248	4779	5310	5841	6372	6903
	B.H.P.	16.6	33.3	166.4	333	666	999	1332	1665	1998	2331	2664	2997	3330	3663	3996	4329
.32	I.H.P.	28.1	56.24	281.2	562	1125	1687	2250	2812	3374	3937	4499	5062	5624	6186	6749	7311
	B.H.P.	17.4	34.86	174.4	349	697	1046	1394	1743	2092	2440	2789	3137	3486	3835	4183	4532
.33	I.H.P.	30.1	60.1	300.5	601	1202	1803	2404	3005	3606	4207	4808	5409	6010	6611	7212	7813
	B.H.P.	18.4	36.7	183.5	367	734	1101	1468	1835	2202	2569	2936	3303	3670	4037	4404	4771
.34	I.H.P.	31.9	63.8	319	638	1276	1914	2552	3190	3828	4466	5104	5742	6380	7018	7656	8294
	B.H.P.	19.3	38.5	192.5	385	770	1155	1540	1925	2310	2695	3080	3465	3850	4235	4620	5005
.35	I.H.P.	33.8	67.5	337.5	675	1350	2025	2700	3375	4050	4725	5400	6075	6750	7425	8100	8775
	B.H.P.	20.2	40.4	202	404	808	1212	1616	2020	2424	2828	3232	3636	4040	4444	4848	5252
.36	I.H.P.	35.8	71.5	357.5	715	1430	2145	2860	3575	4290	5005	5720	6435	7150	7865	8580	9295
	B.H.P.	21.1	42.2	211	422	844	1266	1688	2110	2532	2954	3376	3798	4220	4642	5064	5486
.37	I.H.P.	37.8	75.68	378.4	757	1514	2270	3027	3784	4541	5298	6054	6811	7568	8325	9082	9839
	B.H.P.	22.1	44.12	220.7	441	882	1324	1765	2206	2647	3088	3530	3971	4412	4853	5294	5735
.38	I.H.P.	40.1	80.1	400.5	801	1602	2403	3204	4005	4806	5607	6408	7209	8010	8811	9612	10413
	B.H.P.	23.2	46.5	231.5	463	926	1389	1852	2315	2778	3241	3704	4167	4630	5093	5556	6019
.39	I.H.P.	42.5	85.0	425	850	1700	2550	3400	4250	5100	5950	6800	7650	8500	9350	10200	11050
	B.H.P.	24.3	48.5	242.5	485	970	1455	1940	2425	2910	3395	3880	4365	4850	5335	5820	6305
.40	I.H.P.	45.0	90.0	450	900	1800	2700	3600	4500	5400	6300	7200	8100	9000	9900	10800	11700
	B.H.P.	25.5	50.9	254.5	509	1018	1527	2036	2545	3054	3563	4072	4581	5090	5599	6108	6617
.41	I.H.P.	47.6	95.1	475.5	951	1902	2853	3804	4755	5706	6657	7608	8559	9510	10461	11412	12363
	B.H.P.	26.6	53.2	266	532	1064	1596	2128	2660	3192	3724	4256	4788	5320	5852	6384	6916
.42	I.H.P.	50.3	100.5	502.5	1005	2010	3015	4020	5025	6030	7035	8040	9045	10050	11055	12060	13065
	B.H.P.	27.9	55.74	278.7	557	1115	1672	2230	2787	3344	3902	4459	5017	5574	6131	6689	7246
.43	I.H.P.	53.5	106.6	533	1066	2132	3198	4264	5330	6396	7462	8528	9594	10660	11726	12792	13858
	B.H.P.	29.1	58.25	291.2	583	1165	1748	2330	2913	3495	4078	4660	5243	5825	6408	6990	7573
.44	I.H.P.	56.4	112.8	564	1128	2256	3384	4512	5640	6768	7896	9024	10152	11280	12408	13536	14664
	B.H.P.	30.5	60.9	304.5	609	1218	1827	2436	3045	3654	4263	4872	5481	6090	6699	7308	7917
.45	I.H.P.	59.5	119.0	595	1190	2380	3570	4760	5950	7140	8330	9520	10710	11900	13090	14280	15470
	B.H.P.	31.9	63.7	318.5	637	1274	1911	2548	3185	3872	4459	5096	5733	6370	7007	7644	8281
.46	I.H.P.	62.9	125.8	629	1258	2516	3774	5032	6290	7548	8806	10064	11322	12580	13838	15096	16354
	B.H.P.	33.4	66.8	334	668	1336	2004	2672	3340	4008	4676	5344	6012	6680	7348	8016	8684
.47	I.H.P.	66.5	133.0	665	1330	2660	3990	5320	6650	7980	9310	10640	11970	13300	14630	15960	17290
	B.H.P.	35.1	70.1	350.5	701	1402	2103	2804	3505	4206	4907	5608	6309	7010	7711	8412	9113
.48	I.H.P.	70.5	141.0	705	1410	2820	4230	5640	7050	8460	9870	11280	12690	14100	15510	16920	18330
	B.H.P.	37.0	74.0	370	740	1480	2220	2960	3700	4440	5180	5920	6660	7400	8140	8880	9620
.49	I.H.P.	74.9	149.8	749	1498	2996	4494	5992	7490	8988	10486	11984	13482	14980	16478	17976	19474
	B.H.P.	39.2	78.4	392	784	1568	2352	3136	3920	4704	5488	6272	7056	7840	8624	9408	10192
.50	I.H.P.	79.5	159.0	795	1590	3180	4770	6360	7950	9540	11130	12720	14310	15900	17490	19080	20670
	B.H.P.	41.6	83.1	415.5	831	1662	2493	3324	4155	4986	5817	6648	7479	8310	9141	9972	10803
.51	I.H.P.	84.2	168.3	841.5	1683	3366	5049	6732	8415	10098	11781	13464	15147	16830	18513	20196	21879
	B.H.P.	44.2	88.35	441.7	884	1767	2651	3534	4418	5301	6185	7068	7952	8835	9719	10602	11486
.52	I.H.P.	89.4	178.7	893.5	1787	3574	5361	7148	8935	10722	12509	14296	16083	17870	19657	21444	23231
	B.H.P.	46.9	93.8	469	938	1876	2814	3752	4690	5628	6566	7504	8442	9380	10318	11256	12194
.53	I.H.P.	94.5	189.0	945	1890	3780	5670	7560	9450	11340	13230	15120	17010	18900	20790	22680	24570
	B.H.P.	49.6	99.2	496	992	1984	2976	3968	4960	5952	6944	7936	8928	9920	10912	11904	12896
.54	I.H.P.	99.8	199.6	997.8	1995	3990	5985	7980	9975	11970	13965	15960	17955	19950	21945	23940	25935
	B.H.P.	52.4	104.8	524	1048	2095	3143	4190	5238	6285	7333	8380	9428	10475	11523	12570	13618
M	H.P.	.5	1.0	5.0	10	20	30	40	50	60	70	80	90	100	110	120	130

ERRATA.—Table 2: I.H.P. for $\frac{\text{P.A.}}{\text{D.A.}} = .47$

TABLE 2.

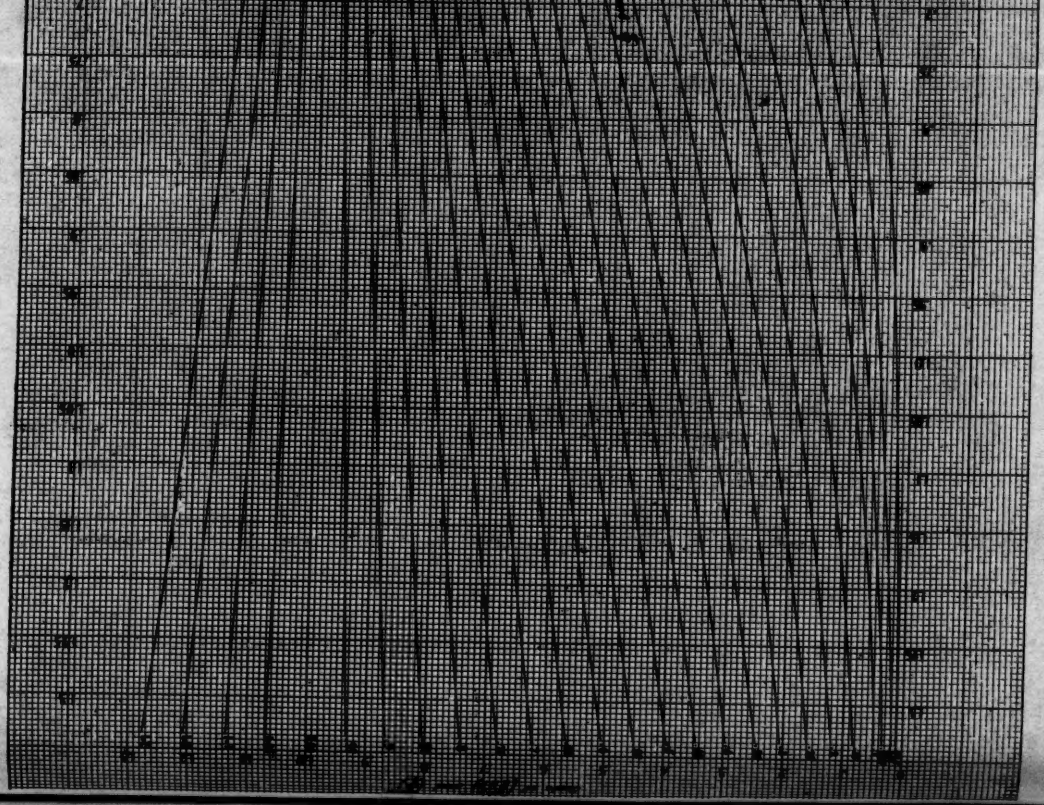
110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	300	350	400	450	P.A. M.
440	1571	1702	1832	1963	2095	2225	2355	2487	2618	2750	2880	3010	3142	3273	3825	4580	5240	5890	IHP
018	1110	1203	1295	1388	1480	1573	1666	1758	1851	1944	2036	2130	2200	2315	2775	3240	3700	4165	EHP .25
806	1782	1898	2044	2190	2333	2482	2628	2774	2920	3066	3212	3358	3504	3650	4380	5110	5840	6570	IHP
132	1235	1338	1441	1544	1646	1750	1853	1955	2060	2160	2265	2368	2470	2573	3088	3603	4116	4630	EHP .24
835	2002	2168	2335	2502	2669	2836	3002	3169	3336	3503	3670	3836	4005	4170	5004	5838	6672	7506	IHP
292	1409	1527	1644	1762	1879	1997	2114	2237	2349	2467	2584	2701	2819	2936	3524	4111	4698	5285	EHP .25
072	2261	2449	2638	2826	3016	3202	3391	3580	3768	3956	4145	4333	4521	4710	5652	6594	7536	8478	IHP
436	1566	1697	1827	1958	2088	2219	2349	2480	2610	2741	2871	3002	3132	3263	3915	4568	5220	5873	EHP .26
282	2501	2709	2918	3126	3334	3543	3751	3960	4168	4376	4585	4793	5002	5210	6252	7294	8336	9378	IHP
590	1734	1879	2023	2168	2312	2457	2601	2746	2890	3035	3179	3324	3468	3613	4335	5058	5780	6503	EHP .27
508	2736	2964	3192	3420	3648	3876	4104	4332	4560	4788	5016	5244	5472	5700	6840	7980	9120	10260	IHP
758	1896	2054	2212	2370	2528	2686	2844	3002	3160	3318	3476	3634	3792	3950	4740	5530	6320	7110	EHP .28
728	2976	3224	3472	3720	3968	4216	4464	4712	4960	5208	5456	5704	5952	6200	7440	8680	9920	11160	IHP
892	2064	2236	2408	2580	2752	2924	3096	3268	3440	3612	3784	3956	4128	4300	5160	6020	6880	7740	EHP .29
977	3247	3518	3788	4059	4330	4600	4871	5141	5412	5683	5953	6224	6494	6765	8118	9471	8240	12177	IHP
031	2215	2400	2584	2769	2954	3138	3323	3507	3692	3877	4061	4246	4430	4615	5538	6461	7384	8307	EHP .30
221	3514	3806	4099	4392	4685	4978	5270	5563	5856	6149	6442	6734	7027	7320	8784	10248	11712	13176	IHP
209	2410	2610	2811	3012	3213	3414	3614	3815	4016	4217	4418	4618	4819	5020	6024	7028	8032	9036	EHP .31
509	3828	4147	4466	4785	5104	5423	5742	6061	6380	6699	7018	7337	7656	7975	9570	11165	12760	14355	IHP
376	2592	2808	3024	3240	3456	3672	3888	4104	4320	4536	4752	4968	5184	5400	6480	7560	8640	9720	EHP .32
905	4260	4615	4970	5325	5680	6035	6390	6745	7100	7455	7810	8165	8520	8875	10650	12425	14200	15975	IHP
550	2760	2990	3220	3450	3680	3910	4140	4370	4600	4830	5060	5290	5520	5750	6900	8050	9200	10350	EHP .33
081	4452	4823	5194	5565	5936	6307	6678	7049	7420	7791	8162	8533	8904	9275	11130	12985	14840	16695	IHP
701	2946	3192	3437	3683	3928	4174	4419	4665	4910	5156	5401	5647	5892	6138	7365	8593	9820	11048	EHP .34
393	4793	5192	5592	5991	6390	6790	7189	7589	7988	8387	8787	9186	9586	9985	11982	13980	15976	17974	IHP
866	3126	3387	3647	3908	4168	4429	4689	4950	5210	5471	5731	5992	6252	6513	7815	9118	10420	11723	EHP .35
752	5184	5616	6048	6480	6912	7344	7776	8208	8640	9072	9504	9936	10368	10800	12960	15120	17280	19440	IHP
058	3336	3614	3892	4170	4448	4726	5004	5282	5560	5838	6116	6394	6672	6950	8340	9730	11200	12510	EHP .36
104	5568	6032	6496	6960	7424	7888	8352	8816	9280	9744	10208	10672	11136	11600	13920	16240	18560	20880	IHP
245	3540	3835	4130	4425	4720	5015	5310	5605	5900	6195	6490	6785	7080	7375	8850	10325	11800	13275	EHP .37
478	5976	6474	6972	7470	7968	8466	8964	9462	9960	10458	10956	11454	11952	12450	14940	17430	19920	22410	IHP
451	3764	4078	4392	4706	5019	5333	5647	5960	6274.	6588	6901	7215	7529	7843	9411	10980	12548	14117	EHP .38
841	6372	6903	7434	7965	8496	9027	9558	10089	10620	11151	11682	12213	12744	13275	15930	18585	21240	23895	IHP
663	3996	4329	4662	4995	5328	5661	5994	6327	6660	6993	7326	7659	7992	8325	9990	11655	13320	14985	EHP .39
186	6749	7311	7874	8436	8998	9561	10123	10686	11248	11810	12373	12935	13498	14060	16872	19684	22496	25308	IHP
835	4183	4532	4880	5229	5578	5926	6275	6623	6972	7321	7669	8018	8366	8715	10458	12201	13944	15687	EHP .40
611	7212	7813	8414	9015	9616	10217	10818	11419	12020	12621	13222	13823	14424	15025	18030	21035	24040	27045	IHP
037	4404	4771	5138	5505	5872	6239	6606	6973.	7340	7707	8074	8441	8808	9175	11010	12845	14680	16515	EHP .41
018	7656	8294	8932	9570	10208	10846	11484	12122	12760	13398	14036	14674	15312	15950	19140	22330	25520	28710	IHP
235	4620	5005	5390	5775	6160	6545	6930	7315	7700	8085	8470	8855	9240	9625	11550	13475	15400	17325	EHP .42
425	8100	8775	9450	10125	10800	11475	12150	12825	13500	14175	14850	15525	16200	16875	20250	23625	27000	30375	IHP
444	4848	5252	5656	6060	6464	6868	7272	7676	8080	8484	8888	9292	9696	10100	12120	14140	16160	18180	EHP .43
865	8580	9295	10010	10725	11440	12155	12870	13585	14300	15015	15730	16445	17160	17875	21450	25025	28600	32175	IHP.
642	5064	5488	5908	6330	6752	7174	7596	8018	8440	8862	9284	9706	10128	10550	12660	14770	16880	18990	EHP .44
325	9082	9838	10595	11352	12109	12866	13622	14379	15136	15892	16650	17406	18163	18920	22704	26488	30272	34056	IHP
853	5294	5736	6177	6618	7059	7500	7942	8383	8824	9265	9706	10148	10589	11030	13236	15442	17648	19854	EHP .45
811	9612	10415	11214	12015	12816	13617	14418	15219	16020	16821	17622	18423	19224	20025	24030	28035	32040	36045	IHP
093	5556	6019	6482	6945	7408	7871	8334	8797	9260	9723	10186	10649	11112	11575	13890	16205	18520	20835	EHP .46
350	10200	11050	11900	12750	13600	14450	15300	16150	17000	17850	18700	19550	20400	21250	25500	29750	34000	38250	IHP .47
335	5820	6305	6790	7275	7760	8245	8730	9215	9700	10185	10670	11155	11640	12125	14550	16975	19400	21825	EHP
900	10800	11700	12600	13500	14400	15300	16200	17100	18000	18900	19800	20700	21600	22500	27000	31500	36000	40500	IHP .48
599	6108	6617	7126	7635	8144	8653	9162	9671	10180	10689	11198	11707	12216	12725	15270	17815	20360	22905	EHP
461	11412	12363	13314	14265	15216	16167	17118	18069	19020	19971	20922	21873	22824	23775	28530	33285	38040	42795	IHP .49
852	6384	6916	7448	7980	8512	9044	9576	10108	10640	11172	11704	12236	12768	13300	15960	18620	21280	23940	EHP
055	12060	13065	14070	15075	16080	17085	18090	19095	20100	21105	22110	23115	24120	25125	30150	35175	40200	45225	IHP .50
131	6689	7246	7804	8361	8918	9476	10033	10590	11148	11705	12263	12820	13378	13935	16722	19509	22296	25083	EHP
726	12792	13858	14924	15990	17056	18122	19188	20254	21320	22386	23452	24518	25584	26650	31980	37310	42640	47970	IHP .51
408	6990	7573	8155	8738	9320	9903	10485	11068	11650	12233	12815	13398	13980	14563	17475	20388	23300	26213	EHP
408	13536	14664	15792	16920	18048	19176	20304	21432	22560	23688	24816	25944	27072	28200	33840	39480	45120	50760	IHP .52
699	7308	7917	8526	9135	9744	10353	10962	11571	12180	12789	13398	14007	14616	15225	18270	21315	24360	27405	EHP
090	14280	15470	16660	17850	19040	20230	21420	22610	23800	24990	26180	27370	28560	29750	35700	41650	47600	53550	IHP .53
007	7644	8281	8918	9555	10192	10829	11466	12103	12740	13377	14014	14651	15288	15925	19110	22295	25480	28665	EHP
838	15096	16354	17612	18870	20128	21386	22644	23902	25160	26418	27676	28934	30192	31450	37740	44030	50320	56610	IHP .54
348	8016	8684	9352	10020	10688	11356	12024	12692	13360	14028	14696	15364	16032	16700	20040	23380	26720	30060	EHP
630	15960	17290	18620	19950	21280	22610	23940	25270	26600	27930	29260	30590	31920	33250	39900	46550	53200	59850	IHP .55
711	8412	9113	9814	10515	11216	11917	12618	13319	14020	14721	15422	16123	16824	17525	21030	24535	28040	31545	EHP
510	16920	18330	19740	21150	22560	23970	25380	26790	28200	29610	31020	32430	33840	35250	42300	49350	56400	63450	IHP .56
840	8880	9620	10360	11100	11840	12580	13320	14060	14800	15400	16280	17020	17760	18500	22200	25900	29600	33300	EHP
478	17976	19474	20972	22470	23968	25466	26964	28462	29960	31458	32956	34454	35952	37450	44940	52430	59920	67410	IHP .57
824	9408	10192	10976	11760	12544	13328	14112	14896	15680	16464	17248	18032	18816	19600	23520	27440	31360	35280	EHP
490	19060	20670	22260	23850	25440	27030	28620	30210	31800	33390	34980	36570	38160	39750	47700	55650	63600	71550	IHP .58
141	9972	10803	11634	12465	13296	14127	14958	15789	16620	17451	18282	19113	19944	20775	24930	29085	33240	37395	EHP
513	20196	21879	23562	25245	26928	28611	30294	31977	33660	35343	37026	38709	40392	42075	50490	58905	67320	75735	IHP .59
019	10602	11486	12369	13253	14136	15020	15903	16787	17670	18554	19437	20321	21204	22088	26505	30923	35340	39758	EHP
657	21444	23231	25018	26805	28592	30379	32166	33953	35740	37527	39314	41101	42888	44676	53610	62545	71480	80415	IHP .60
318	11256	12194	13132	14070	15008	15948	16884	17822	18760	19698	20636	21574	22512	23450	28140	32830	37520	42210	EHP
790	22680	24570	26460	28350	30240	32130	34020	35910	37800	39690	41580	43470	45360	47250	56700	66150	75600	85050	IHP .61
912	11904	12896	13888	14880	15872	16864	17856	18848	19840	20832	21824	22816	23808	24800	29760	34720	39680	44640	EHP
945	23940	25935	27930	29925	31920	33915	35910	37905	39900	41895	43890	45885	47880	49875	59850	69825	79800	89775	IHP .62
523	12570	13618	14665	15713	16760	17808	18855	19903	20950	21998	23045	24093	25140	26188	31425	36663	41900	47138	EHP
110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	300	350	400	450	P.I.D.

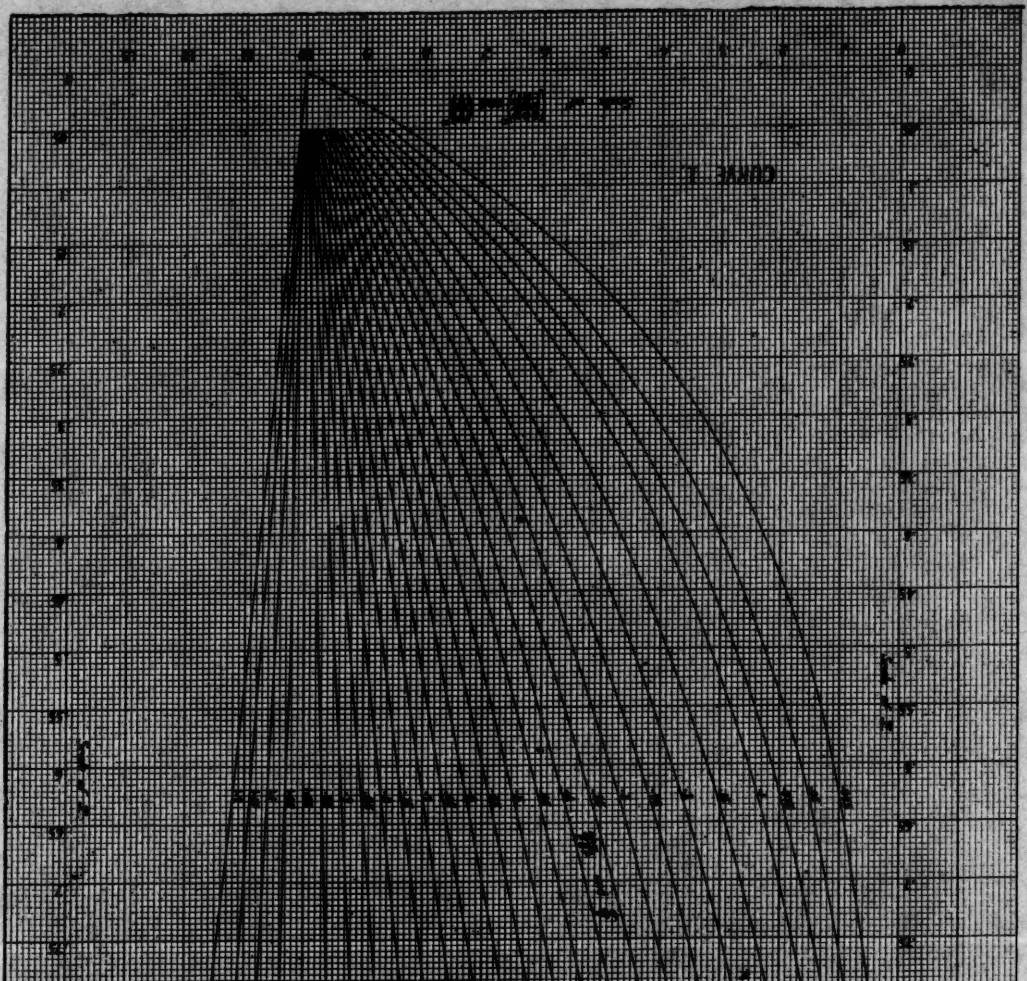
$\frac{A.}{A.} = .47$, and $P \times .D = 110$ should be 5,335 instead of 6,335.

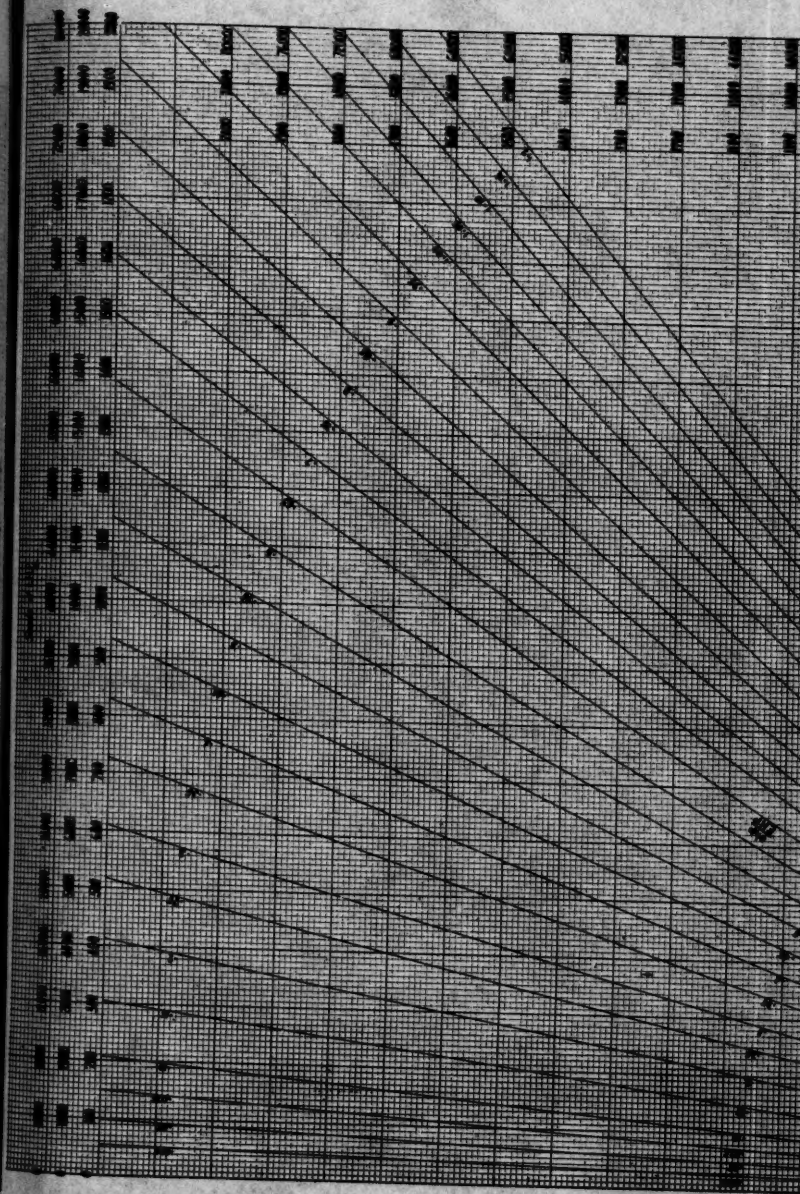
TABLE 3—V.

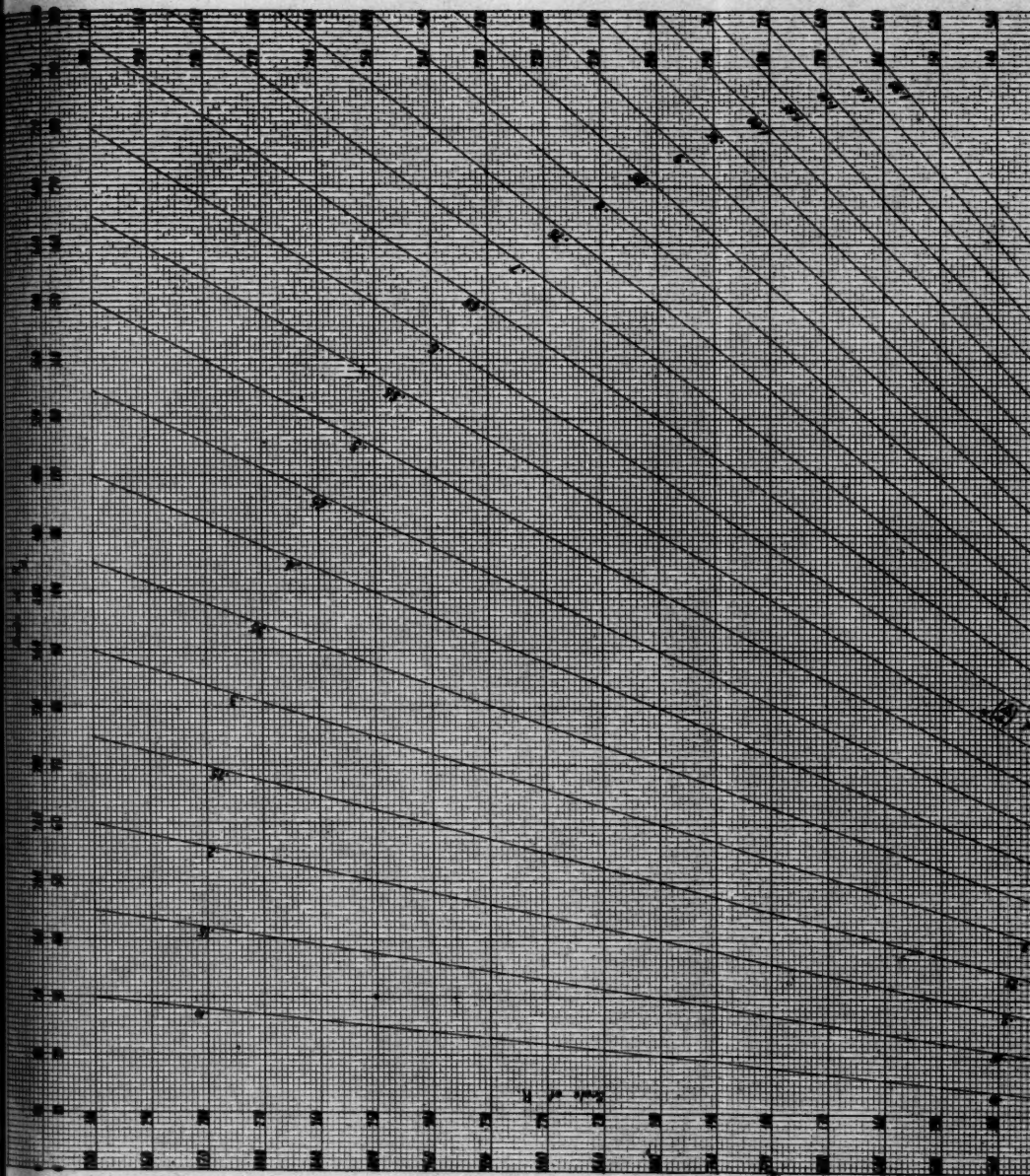
Pa	p	.3	.35	.4	.45	.5	.55	.6	.65	.7	.75	.8	.85	.9
	.8			10.89	10.99	11.08	11.21	11.34	11.46	11.61	11.75	11.9	12.02	12.17
	.9			12.25	12.35	12.47	12.61	12.75	12.91	13.06	13.22	13.37	13.53	13.7
.23	1.0			13.61	13.74	13.86	14.02	14.19	14.35	14.52	14.7	14.87	15.04	15.22
	1.1			14.96	15.1	15.24	15.41	15.58	15.77	15.98	16.15	16.35	16.53	16.73
	1.2			16.33	16.48	16.63	16.82	17.00	17.21	17.42	17.63	17.84	18.04	18.25
	1.3			17.69	17.85	18.00	18.21	18.42	18.63	18.86	19.1	19.32	19.54	19.77
	.8			11.43	11.54	11.64	11.77	11.9	12.05	12.2	12.36	12.49	12.63	12.78
	.9			12.86	12.97	13.1	13.24	13.39	13.56	13.72	13.88	14.05	14.21	14.37
.24	1.0			14.3	14.42	14.55	14.72	14.88	15.07	15.25	15.43	15.62	15.79	15.98
	1.1			15.72	15.86	16.00	16.18	16.36	16.57	16.78	16.96	17.17	17.37	17.57
	1.2			17.15	17.3	17.46	17.66	17.84	18.06	18.29	18.52	18.75	18.95	19.17
	1.3			18.57	18.74	18.92	19.14	19.34	19.58	19.85	20.05	20.32	20.55	20.77
	.8			11.98	12.11	12.21	12.36	12.47	12.63	12.77	12.93	13.08	13.24	13.4
	.9			13.48	13.62	13.75	13.9	14.02	14.2	14.36	14.54	14.72	14.89	15.06
.25	1.0			14.97	15.13	15.28	15.44	15.58	15.78	15.96	16.16	16.35	16.55	16.74
	1.1			16.47	16.64	16.81	16.98	17.14	17.36	17.56	17.77	17.98	18.2	18.41
	1.2			17.97	18.16	18.34	18.53	18.7	18.95	19.15	19.4	19.62	19.85	20.09
	1.3			19.46	19.67	19.86	20.07	20.25	20.51	20.73	21.01	21.24	21.52	21.76
	.8			12.5	12.64	12.76	12.92	13.04	13.19	13.34	13.5	13.66	13.83	13.98
	.9			14.06	14.22	14.35	14.5	14.67	14.84	15.01	15.19	15.37	15.56	15.73
.26	1.0			15.63	15.8	15.98	16.16	16.3	16.49	16.68	16.88	17.08	17.29	17.48
	1.1			17.19	17.38	17.58	17.78	17.93	18.14	18.35	18.57	18.79	19.02	19.23
	1.2			18.76	18.96	19.18	19.39	19.56	19.79	20.02	20.26	20.5	20.75	20.98
	1.3			20.32	20.54	20.77	21.01	21.19	21.44	21.69	21.94	22.2	22.46	22.72
	.8			13.0	13.14	13.28	13.44	13.57	13.73	13.87	14.03	14.2	14.38	14.54
	.9			14.63	14.78	14.96	15.15	15.28	15.45	15.62	15.8	15.98	16.18	16.36
.27	1.0			16.25	16.43	16.63	16.81	16.96	17.16	17.34	17.54	17.73	17.98	18.16
	1.1			17.88	18.07	18.29	18.49	18.65	18.86	19.07	19.29	19.52	19.78	20.00
	1.2			19.50	19.72	19.96	20.17	20.34	20.57	20.81	21.05	21.3	21.58	21.82
	1.3			21.13	21.36	21.62	21.85	22.04	22.28	22.54	22.8	23.08	23.37	23.63
	.8			13.49	13.62	13.79	13.94	14.08	14.25	14.4	14.58	14.75	14.9	15.09
	.9			15.18	15.32	15.51	15.68	15.82	16.01	16.2	16.37	16.57	16.76	16.96
.28	1.0			16.86	17.08	17.24	17.45	17.58	17.79	18.00	18.19	18.41	18.63	18.86
	1.1			18.56	18.73	18.96	19.17	19.34	19.57	19.8	20.01	20.25	20.48	20.75
	1.2			20.23	20.44	20.69	20.88	21.10	21.35	21.6	21.82	22.09	22.36	22.63
	1.3			21.92	22.14	22.41	22.66	22.85	23.15	23.4	23.65	23.93	24.23	24.53
	.8			13.98	14.09	14.26	14.41	14.54	14.75	14.89	15.05	15.25	15.44	15.6
	.9			15.69	15.85	16.05	16.21	16.38	16.57	16.73	16.98	17.15	17.37	17.55
.29	1.0			17.44	17.61	17.83	18.01	18.2	18.42	18.61	18.81	19.06	19.3	19.5
	1.1			19.18	19.37	19.61	19.81	20.02	20.25	20.47	20.69	20.97	21.23	21.48
	1.2			20.92	21.15	21.4	21.61	21.84	22.09	22.33	22.57	22.87	23.16	23.46
	1.3			22.67	22.93	23.19	23.41	23.66	23.93	24.19	24.46	24.78	25.09	25.43
	.8			14.4	14.53	14.72	14.87	15.02	15.21	15.37	15.54	15.74	15.93	16.14
	.9			16.2	16.4	16.56	16.75	16.92	17.12	17.29	17.51	17.71	17.95	18.16
.30	1.0			18.0	18.2	18.36	18.6	18.8	19.02	19.18	19.42	19.68	19.94	20.17
	1.1			19.8	20.08	20.25	20.48	20.68	20.92	21.15	21.4	21.65	21.96	22.19
	1.2			21.6	21.86	22.07	22.32	22.55	22.83	23.07	23.35	23.62	23.93	24.2
	1.3			23.4	23.66	23.91	24.18	24.44	24.73	24.99	25.29	25.59	25.92	26.23
	.8			14.84	14.96	15.15	15.3	15.46	15.66	15.82	16.04	16.24	16.44	16.4
	.9			16.7	16.87	17.05	17.22	17.42	17.64	17.81	18.05	18.27	18.5	18.68
.31	1.0			18.55	18.74	18.94	19.13	19.35	19.6	19.79	20.05	20.3	20.56	20.75
	1.1			20.41	20.61	20.83	21.04	21.29	21.56	21.77	22.06	22.33	22.62	22.83

Pa	p	.3	.35	.4	.45	.5	.55	.6	.65	.7	.75	.8	.85	.9
	.8			19.4	19.61	19.85	20.05	20.26	20.48	20.75	21.02	21.3		
	.9			22.02	22.06	22.31	22.55	22.8	23.04	23.36	23.65	23.97		
.42	1.0			24.25	24.51	24.78	25.06	25.33	25.6	25.94	26.28	26.63		
	1.1			26.46	26.96	27.27	27.57	27.84	28.16	28.53	28.91	29.29		
	1.2			29.1	29.41	29.75	30.07	30.4	30.72	31.13	31.54	31.96		
	1.3			31.52	31.86	32.23	32.56	32.96	33.28	33.72	34.16	34.62		
	.8			19.75	19.96	20.19	20.41	20.64	20.87	21.15	21.43	21.7		
	.9			22.22	22.46	22.72	22.96	23.22	23.48	23.77	24.08	24.42		
.43	1.0			24.69	24.95	25.24	25.51	25.8	26.09	26.41	26.76	27.13		
	1.1			27.16	27.45	27.76	28.06	28.36	28.7	29.05	29.44	29.84		
	1.2			29.63	29.94	30.29	30.61	30.96	31.31	31.69	32.11	32.56		
	1.3			32.1	32.44	32.81	33.16	33.54	33.92	34.33	34.79	35.27		
	.8			20.09	20.32	20.53	20.76	21.00	21.23	21.5	21.81	22.06		
	.9			22.6	22.86	23.1	23.36	23.63	23.89	24.2	24.54	24.84		
.44	1.0			25.1	25.4	25.68	25.96	26.23	26.54	26.9	27.28	27.6		
	1.1			27.62	27.95	28.23	28.54	28.83	29.2	29.58	29.98	30.35		
	1.2			30.12	30.49	30.8	31.15	31.49	31.86	32.25	32.71	33.12		
	1.3			32.63	33.02	33.34	33.73	34.12	34.5	34.92	35.44	35.88		
	.8			20.44	20.69	20.9	21.15	21.38	21.62	21.9				
	.9			23.0	23.27	23.52	23.8	24.06	24.32	24.63				
.45	1.0			25.55	25.86	26.13	26.44	26.73	27.02	27.37				
	1.1			28.11	28.45	28.74	29.08	29.4	29.72	30.11				
	1.2			30.66	31.03	31.36	31.73	32.08	32.42	32.84				
	1.3			33.21	33.62	33.97	34.37	34.73	35.13	35.58				
	.8			20.81	21.07	21.29	21.52	21.76	22.02	22.3				
	.9			23.41	23.71	23.95	24.23	24.49	24.77	25.08				
.46	1.0			26.01	26.34	26.61	26.9	27.2	27.52	27.87				
	1.1			28.61	28.97	29.27	29.59	29.92	30.27	30.66				
	1.2			31.21	31.61	31.93	32.28	32.64	33.02	33.44				
	1.3			33.81	34.24	34.59	34.97	35.36	35.78	36.23				
	.8			21.19	21.46	21.68	21.92	22.16	22.42	22.7				
	.9			23.84	24.14	24.39	24.66	24.93	25.23	25.54				
.48	1.0			26.48	26.82	27.1	27.4	27.7	28.03	28.38				
	1.1			29.14	29.49	29.81	30.14	30.47	30.83	31.22				
	1.2			31.79	32.18	32.52	32.88	33.24	33.64	34.06				
	1.3			34.44	34.87	35.23	35.62	36.01	36.44	36.89				
	.8	21.04	21.31	21.55	21.8	22.04	22.3	22.58	22.86	23.17				
	.9	23.7	23.98	24.27	24.57	24.84	25.11	25.4	25.7	26.02				
.49	1.0	26.35	26.64	26.97	27.3	27.6	27.9	28.22	28.55	28.91				
	1.1	28.98	29.3	29.67	30.03	30.36	30.69	31.04	31.41	31.8				
	1.2	31.6	31.97	32.36	32.76	33.12	33.48	33.86	34.26	34.69				
	1.3	34.23	34.63	35.05	35.49	35.88	36.27	36.68	37.12	37.58				
	.8	21.97	21.75	21.55	21.35	21.18	21.74	21.55	21.35	21.16				
	.9	24.17	24.44	24.75	25.05	25.32	25.57	25.88	24.19	24.52				
.50	1.0	26.85	27.16	27.5	27.82	28.12	28.42	28.75	29.1	29.47				
	1.1	29.55	29.88	30.25	30.6	30.92	31.25	31.63	32.01	32.43				
	1.2	32.22	32.59	33.0	33.38	33.73	34.1	34.5	34.92	35.39				
	1.3	34.93	35.31	35.74	36.17	36.57	36.98	37.38	37.83	38.31				
	.8	21.5	22.15	22.41	22.68	22.95	23.18	23.44	23.72	24.04				
	.9	24.18	24.48	25.21	25.52	25.79	26.07	26.37	26.69	27.06				
.51	1.0	26.87	27.69	28.01	28.35	28.66	28.97	29.3	29.65	30.05				
	1.1	29.56	29.89	30.81	31.19	31.55	31.97	32.33	32.62	33.04				

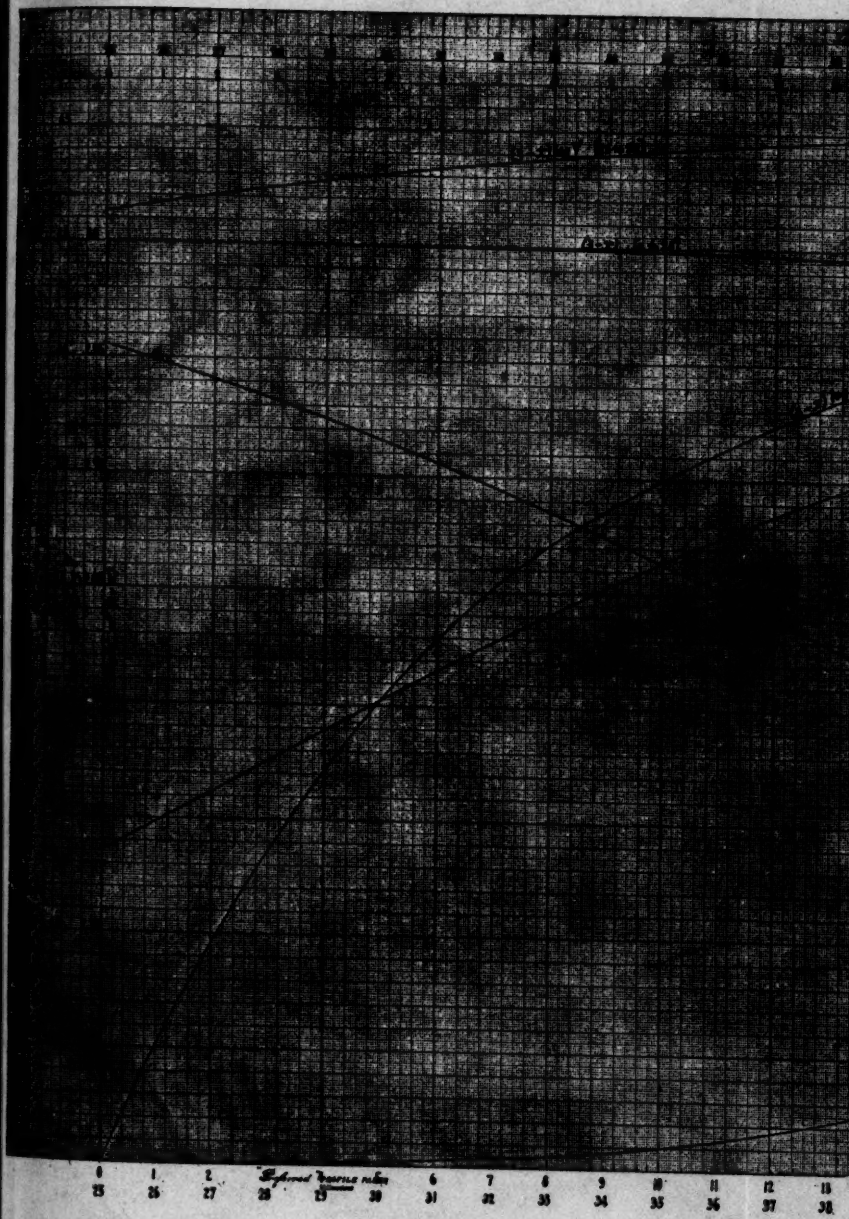








CURVE 3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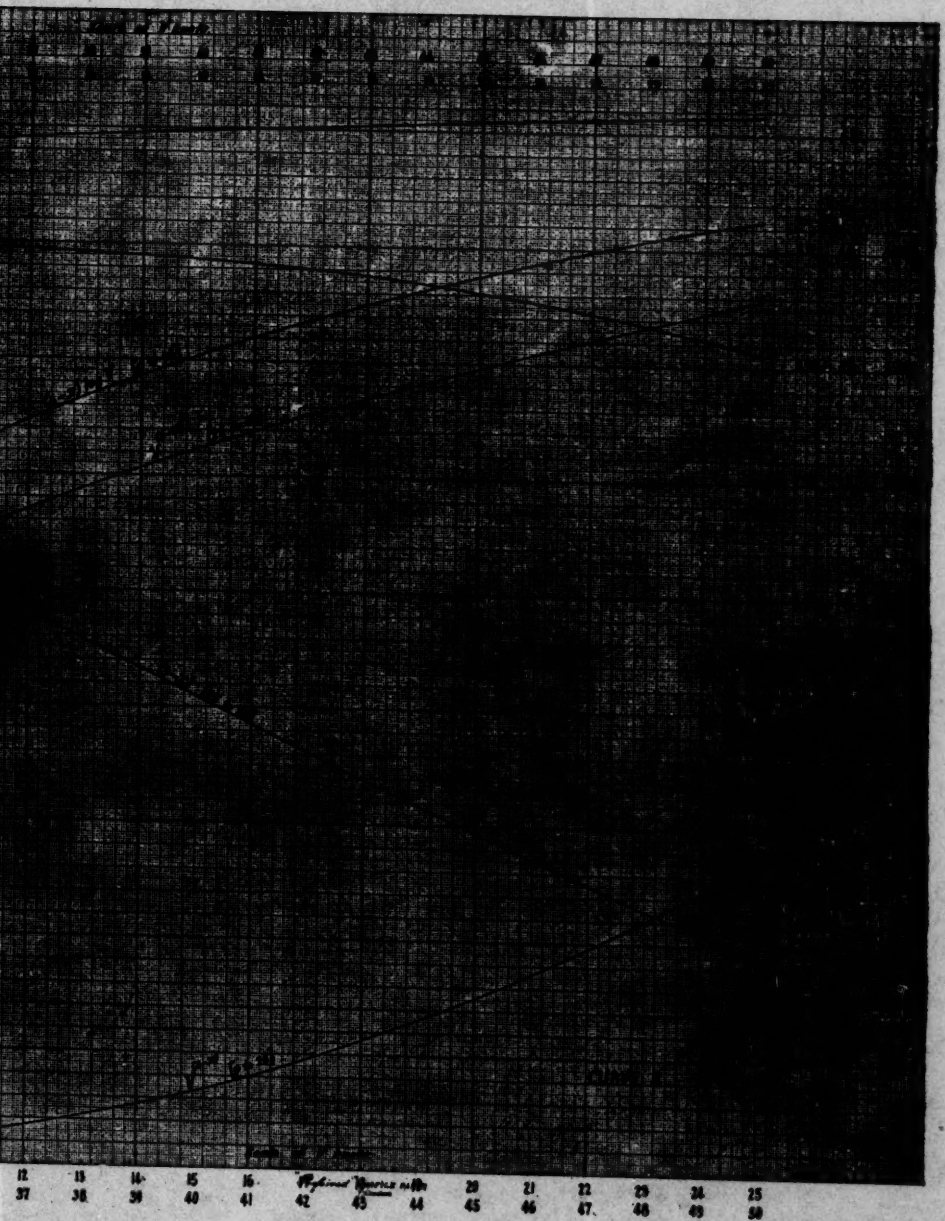
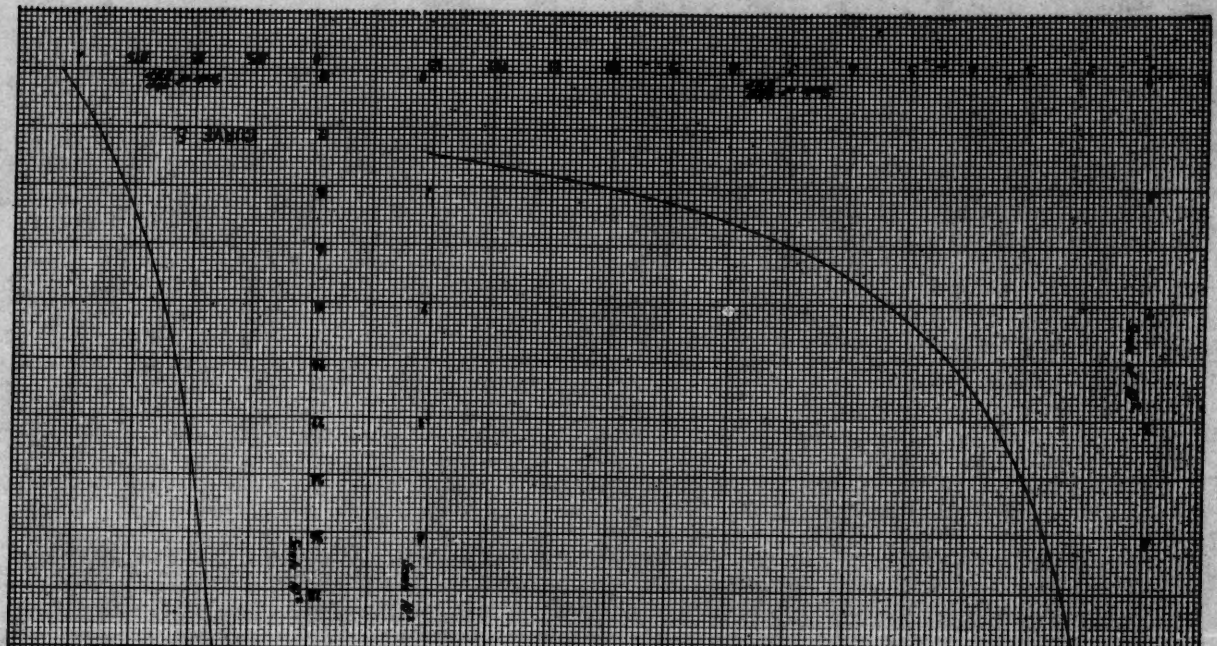




$\frac{P.A.}{D.A.}$	.56	.58	.60
$e.h.p.$	4,075	4,075	4,075
$\frac{e.h.p.}{E.H.P.}$	1	1	1
E.H.P.	4,075	4,075	4,075
P.C.	.525	.525	.525
I.H.P.	7,770	7,770	7,770
I.T.p	10.58	11.27	12.0
D	7.25	7.25	7.25
D^2	52.58	52.58	52.58
P × R	4,073	3,825	3,590
1 − S	.805	.795	.785
V	32.35	30.0	27.80
v	29.5	29.5	29.5
$\frac{v}{V}$	.912	.983	1.06
πD	22.77	22.77	22.77
T.S.	12,180	12,870	13,650
P × R	4,073	3,825	3,590
P	7.61	6.77	5.99
R	535	565	600
x	.565	.700	.85
$\left(\frac{v}{V}\right)^x$	.95	.99	1.05
R_d	508	559	630

Plot these values in Fig. 3 and we find that P = 6.40 when $R_d = 588$.

Continue the design with form 2 as follows:

$\frac{P.A.}{D.A.}$	.58	.59	.60
D	7.25	7.25	7.25
πD	22.77	22.77	22.77
T.S.	12,870	13,220	13,650
R	565	581	600
P	6.40	6.40	6.40
P × R	3,615	3,720	3,840
D^2	52.58	52.58	52.58
I.T.p	11.27	11.61	12.00
I.H.P.	7,330	7,780	8,300
P.C.	.525	.525	.525
E.H.P.	3,848	4,085	4,360
$e.h.p.$	4,075	4,075	4,075
$\frac{e.h.p.}{E.H.P.}$	1.060	.998	.935

$1-S$	.795	.790	.785
$P \times R$	3,615	3,720	3,840
V	28.35	29.00	29.75
v	29.5	29.5	29.5
$\frac{v}{V}$	1.04	1.017	.992
x	.81	.77	.325
$\left(\frac{e.h.p.}{E.H.P.}\right)^x$	1.044	1.01305	.98
R	565	581	600
R_d	589	588.5	589
I.H.P. (total)	14,660	15,560	16,600
S.H.P. (total)	13,500	14,320	15,280
10^x	.95	1.01	1.08
$S.H.P._d$	14,300	14,310	14,150

Take $\frac{P.A.}{D.A.} = .6$ since this gives better efficiency and better protection against cavitation. It will not be necessary to plot these values as the best design point is obvious. The data for the propeller will be:

$\frac{P.A.}{D.A.} = .6$ $\qquad$ $\frac{v}{V} = .992$

$D = 7.25$ $\qquad$ $\frac{e.h.p.}{E.H.P.} = .935$

$P = 6.4$ $\qquad$ $R = 600$

$S.H.P. = 15{,}270$ $\qquad$ $R_d = 588$

$S.H.P._d = 14{,}150$ $\qquad$ $K = 1$

$V = 29.75$

The same problem will now be solved by the tables.

$L.W.L. = 300$ $\qquad$ $N.B.C. = .415$

$B = 30.5$ $\qquad$ $St.B.C. = .38$

$D' = 9.417$ $\qquad$ $C\,\mathfrak{D} = .684$

$P.S. = 1{,}020$ $\qquad$ $S.B.C. = .38$

$v = 29.5$ $\qquad$ $e.h.p. = 8{,}150$

$R_d = 588$ $\qquad$ $e.h.p.$ (1 shaft) $= 4{,}075$

$\frac{B}{L.W.L.} = .1017$ $\qquad$ $D = 7.25$

$\frac{P.A.}{D.A.}$	.56	.58	.60
$\frac{e.h.p.}{E.H.P.}$	1	1	1
e.h.p. and E.H.P	4,075	4,075	4,075
P × D	55.07	49.04	43.44
D	7.25	7.25	7.25
P	7.6	6.765	5.993
$\frac{P}{D}$	1.048	.933	.8265
S.B.C.	.38	.38	.38
V	32.34	30.07	27.78
v	29.5	29.5	29.5
$\frac{v}{V}$	.912	.981	1.061
x	.565	.700	.85
$\left(\frac{v}{V}\right)^x$	.95	.99	1.05
$\sqrt{K}$	1	1	1
R	535.3	565.5	600
R_d	508.1	559.2	630

These values again coincide with those obtained by calculation. The final computation may now be obtained as follows:

$\frac{P.A.}{D.A.}$	.58	.59	.60
D	7.25	7.25	7.25
P	6.4	6.4	6.4
P × D	46.4	46.4	46.4
I.H.P.	7,378	7,809	8,292
E.H.P.	3,856	4,100	4,352
e.h.p.	4,075	4,075	4,075
$\frac{e.h.p.}{E.H.P.}$	1.057	.995	.937
$\frac{P}{D}$	.8825	.8825	.8825
S.B.C.	.38	.38	.38
V	28.43	29.04	29.67
v	29.5	29.5	29.5
$\frac{v}{V}$	1.0375	1.016	.993
x	.81	.77	.325
$\left(\frac{e.h.p.}{E.H.P.}\right)^x$	1.044	1.01305	.98
$\sqrt{K}$	1	1	1
R	565.5	581	600
R_d	589	588.5	589
S.H.P. (total)	13,560	14,370	15,275
K	1	1	1
$S.H.P._d$	14,350	14,350	14,150

These values are practically the same as those obtained by calculation.

The forms already given must be modified slightly for calculating a four-bladed screw, owing to the fact that all data used is taken off for $\frac{3}{4}$ the actual $\frac{P.A.}{D.A.}$ except the P.C. (propulsive coefficient) which is taken off for the actual $\frac{P.A.}{D.A.}$, and also that the valve of I.H.P. must be multiplied by .865 in the equation for diameter.

In some cases of propeller design the data given is not as complete as that used for the preceding problems, but includes only the hull data and the revolutions and horsepower of the engines, with an approximation of the speed it is expected to obtain.

The next example worked out shows the method used both for the four-bladed screw and also incomplete data.

Data Given:

S.B.C. = .805,
v = 10 knots (estimated),
K × I.H.P.$_d$ = 1,400 (designed horsepower),
K = 1.28 (sheet C, Dyson's charts),
I.H.P.$_d$ = 1,094,
R_d = 75 (designed R.P.M.),
D = 15 feet, 4 inches = 15.333 feet.

$\frac{P.A.}{D.A.}$ (assumed)	.23	.25	.27
$\frac{e.h.p.}{E.H.P.}$ (assumed)	.3	.3	.3
I.H.P.$_d$	1,094	1,094	1,094
I.H.P. (curve 2)	3,950	3,950	3,950
.865 × I.H.P.	3,417	3,417	3,417
P × D (table 2)	252.21	204.85	163.96
D (assumed)	15.333	15.333	15.333
P	16.45	13.36	10.69
$\frac{P}{D}$	1.073	.8715	.697
S.B.C.	.805	.805	.805
V	15.97	13.27	12.38

v (estimated)	10	10	10
$\frac{v}{V}$	.626	.754	.807
x	.425	.297	.243
$\left(\frac{e.h.p.}{E.H.P.}\right)^x$	.6	.7	.746
$\sqrt{K}$	1.13	1.13	1.13
R	103.8	114.2	124.4
R_d	70.3	90.3	104.8

Plotting these values of P and R_d it will be found that a P of 15.7 feet gives 75 R.P.M. which is desired. The value of $\frac{P.A.}{D.A.}$ can now be calculated as follows:

$\frac{P.A.}{D.A.}$	.23	.25	.27
P	15.7	15.7	15.7
D	15.333	15.333	15.333
P × D	240.8	240.8	240.8
I.H.P. (table 1)	3,152.5	4,016.5	5,018.3
$\frac{I.H.P.}{.865}$	3,645	4,645	5,800
$I.H.P._d$	1,094	1,094	1,094
$\frac{e.h.p.}{E.H.P.}\left(\text{curve 2 for } \frac{I.H.P.}{.865}\right)$	.325	.252	.202
$E.H.P. = \frac{I.H.P.}{.865} \times P.C.\left(\text{for } \frac{4}{3}\frac{P.A.}{D.A.}\right)$	2,474	3,080	3,745
$e.h.p.$	804	770	749
$\frac{P}{D}$	1.0235	1.0235	1.0235
S.B.C.	.805	.805	.805
V	15.23	16.76	18.18
v	10	10	10
$\frac{v}{V}$	.6565	.597	.550
x	.405	.405	.405
$\left(\frac{e.h.p.}{E.H.P.}\right)^x$	.638	.578	.530
R	103.8	114.2	124.4
$\sqrt{K}$	1.13	1.13	1.13
R_d	75	74.5	74.6

The value of $\frac{P.A.}{D.A.}$ giving the largest value of $e.h.p.$ is

$\frac{P.A.}{D.A.} = .23$. The data for the screw will be:

$\frac{P.A.}{D.A.} = \frac{4}{8} \times .23 = .3067$ $\quad v = 10$

$D = 15$ ft. 4 ins. $\quad \frac{v}{V} = .6565$

$P = 15$ ft. $8\frac{3}{8}$ ins. $\quad \frac{e.h.p.}{E.H.P.} = .325$

$K \times I.H.P._d = 1{,}400$ $\quad I.H.P. = 3{,}645$

$R_d \times 75$

The foregoing examples cover the majority of cases that arise in propeller design, but the tables can be used for any variation desired, and that they are accurate is shown by the comparison with the calculations.

These tables can also be used for getting the chart condition of a screw very quickly. Take for example the following screw:

Data Given:

$\frac{P.A.}{D.A.} = .39$ $\quad P = 13.61$

$D = .13$ $\quad S.B.C. = .615$

To obtain the chart condition:

$R = 205.6$ (Table 1) $\quad E.H.P. = 23{,}560$ (Table 2)

$P \times D = 176.9$ $\quad \frac{P}{D} = 1.047$

$I.H.P. = 37{,}564$ (Table 2) $\quad S.B.C. = .615$

$S.H.P. = 34{,}400$ $\quad V = 24.6$

In analyzing the results of propeller performances it has been found that the slip at various loads and speeds conforms to the following law:

$$s\,(\text{slip}) = \frac{S\ (\text{chart slip}) \times V\ (\text{chart}) \times I.H.P._d\ (\text{or } S.H.P._d)}{v^{3-x} \times I.H.P.\ (\text{chart})\ (\text{or } S.H.P.)}$$

In this equation S = slip under chart conditions as given in sheet D of Dyson's charts, s = slip at any given speed, I.H.P. (or S.H.P.) = chart horsepower, $I.H.P._d$ (or $S.H.P._d$) = power at the given speed, V = chart speed, and v = any given speed. The exponent x is given by the following curve:

$$b^4v^4x - ab^4v^4 + a^2x = 0.$$

In this equation x is the exponent given above, v is speed, and b and a are constants. This equation can be reduced to the form $x = \frac{av^4b^4}{v^4b^4 + a^2} = \frac{av^4}{v^4 + \frac{a^2}{b^4}}$.

Let $\frac{a^2}{b^4} = c$.

Then $x = \frac{av^4}{v^4 + c}$.

The constants become $a = .5$ and $c = 4 \times 10^6$, so we have $x = \frac{.5\, v^4}{v^4 + (4 \times 10^6)}$.

The values of x are given in curve 4 as are also the values of $(3 - x) \log v$ and v^{3-x}.

To show the accuracy of this curve the following comparison of actual and estimated revolutions is given.

(1) Destroyer (Twin screw).

Speed.	Actual r.p.m.	Est. r.p.m.	Frac. error.
32	496.7	496.0	.0014
27	385	388	.008
24	332	331	.003
21	278	278.1	.0004
17	221.8	221.8	0
13	168	168.25	.0015
10	129.3	131	.014

(2) Gunboat (single screw).

Speed.	Actual r.p.m.	Est. r.p.m.	Frac. error.
13	132.2	132.4	.0015
12	120.5	121.5	.009
8	79	80.3	.016

(3) Merchant ship (slow speed) (single screw).

Speed.	Actual r.p.m.	Est. r.p.m.	Frac. error.
11.12	78.2	79.2	.013
10.455	73	74.3	.018
8.87	61.63	63	.022

(4) Battleship (4 screws).

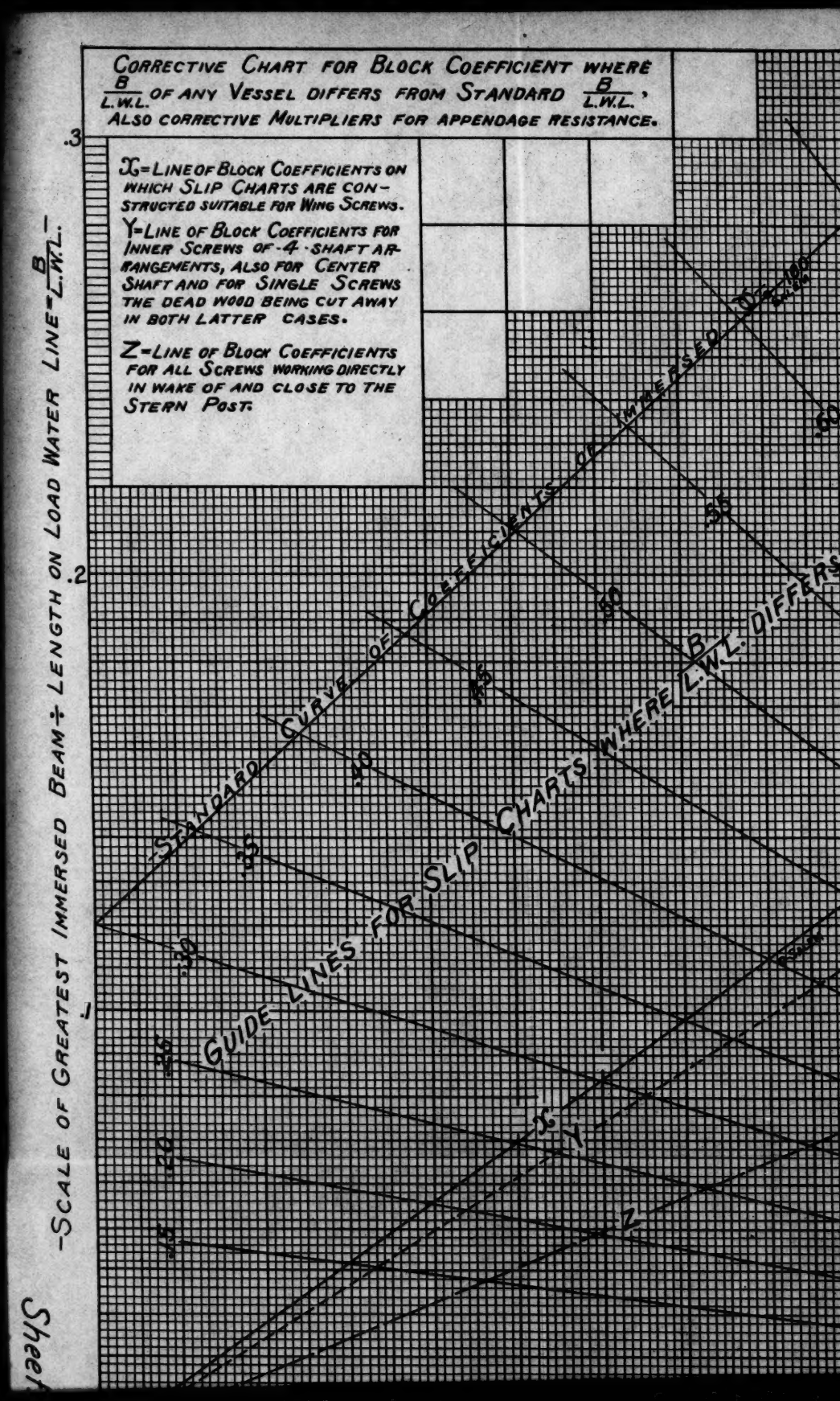
Speed.	Actual r.p.m.	Est. r.p.m.	Frac. error.
21.3	331.5	331	.0015
21.13	326	327.1	.0034
20.7	315	314.6	.0013
20.1	302.5	303.1	.002
19.32	288.5	288.1	.0014
18.42	274.5	273.1	.005
17.44	259	257.2	.007
16.3	241	239.7	.0054
14.81	218	217.1	.0041
12.96	189.5	190.1	.0032
10.31	153	148.8	.027

(5) Battleship (two screws).

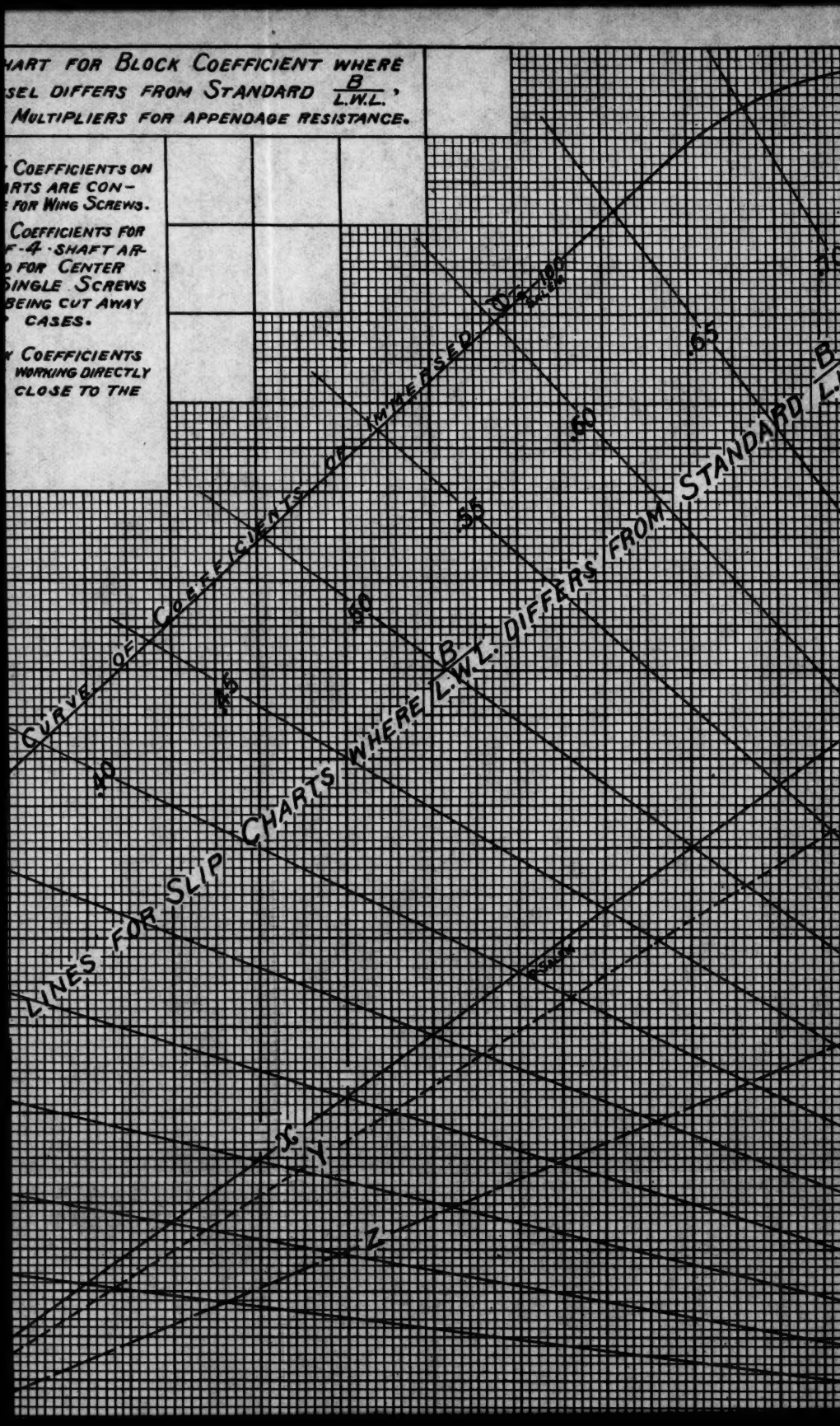
Speed.	Actual r.p.m.	Est. r.p.m.	Frac. error.
21.04	123.9	121.2	.022
20.81	121.7	119.3	.02
20.6	120.0	118.0	.017
20.08	115.8	114.2	.014
19.42	111.0	110.3	.0063
18.61	106.2	105.3	.008
17.7	101.5	99.6	.0187
16.7	95.1	94	.011
15.51	87.4	88.1	.008
14.15	79	79	.0
12.35	69	68.9	.0015
9.55	52	54.2	.042

This curve can also be used for obtaining revolutions in the original design of screws instead of using the value of $\left(\frac{e.h.p.}{E.H.P.}\right)^x$. When used in this way the form of the equation can be simplified as the actual I.H.P.$_d$ becomes K $\times$ I.H.P.$_d$ and $\frac{K \times I.H.P._d}{I.H.P.} = \frac{K}{10^z}$, so we have $s = \frac{S \times V^{3-x} \times K}{10^z \times v^{3-x}}$; we can then use this equation to obtain R_d.

To illustrate this method take the case of the battleship in the first part of this paper.


CORRECTIVE CHART FOR BLOCK COEFFICIENT WHERE B/L.W.L. OF ANY VESSEL DIFFERS FROM STANDARD B/L.W.L., ALSO CORRECTIVE MULTIPLIERS FOR APPENDAGE RESISTANCE.
X=LINE OF BLOCK COEFFICIENTS ON WHICH SLIP CHARTS ARE CONSTRUCTED SUITABLE FOR WING SCREWS.
Y=LINE OF BLOCK COEFFICIENTS FOR INNER SCREWS OF 4-SHAFT ARRANGEMENTS, ALSO FOR CENTER SHAFT AND FOR SINGLE SCREWS THE DEAD WOOD BEING CUT AWAY IN BOTH LATTER CASES.
Z=LINE OF BLOCK COEFFICIENTS FOR ALL SCREWS WORKING DIRECTLY IN WAKE OF AND CLOSE TO THE STERN POST.
-SCALE OF GREATEST IMMERSED BEAM ÷ LENGTH ON LOAD WATER LINE = B/L.W.L.-
.3
.2
1
.80
.70
.60
.50
.40
.30
.20
.10
STANDARD CURVE OF COEFFICIENTS OF AMIDSHIPS SECTION
GUIDE-LINES FOR SLIP CHARTS WHERE L.W.L. B DIFFERS
X
Y
Z

FFERS FROM STANDARD B.
L.W.L.
30
65
70
75
80
85
90
E
B
A


HART FOR BLOCK COEFFICIENT WHERE
SEL DIFFERS FROM STANDARD B/L.W.L.,
MULTIPLIERS FOR APPENDAGE RESISTANCE.
COEFFICIENTS ON
RTS ARE CON-
FOR WING SCREWS.
COEFFICIENTS FOR
F-4 SHAFT AR-
O FOR CENTER
SINGLE SCREWS
BEING CUT AWAY
CASES.
COEFFICIENTS
WORKING DIRECTLY
CLOSE TO THE
CURVE OF COEFFICIENTS OF MODELS BASED ON
.65
.60
.55
.50
.45
.40
LINES FOR SLIP CHARTS WHERE L.W.L. DIFFERS FROM STANDARD B
X
Y
Z

.80
.85
.90
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
-SCALE OF COEFFICIENT OF IMMERSED
A
B
E

TANGENTS, ALSO FOR CENTER SHAFT AND FOR SINGLE SCREWS THE DEAD WOOD BEING CUT AWAY IN BOTH LATTER CASES.

Z - LINE OF BLOCK COEFFICIENTS FOR ALL SCREWS WORKING DIRECTLY IN WAKE OF AND CLOSE TO THE STERN POST.

STANDARD CURVE OF COEFFICIENTS OF IMMERSED SECTION

GUIDE-LINES FOR SLIP CHARTS WHERE L.W.L. DIFFERS

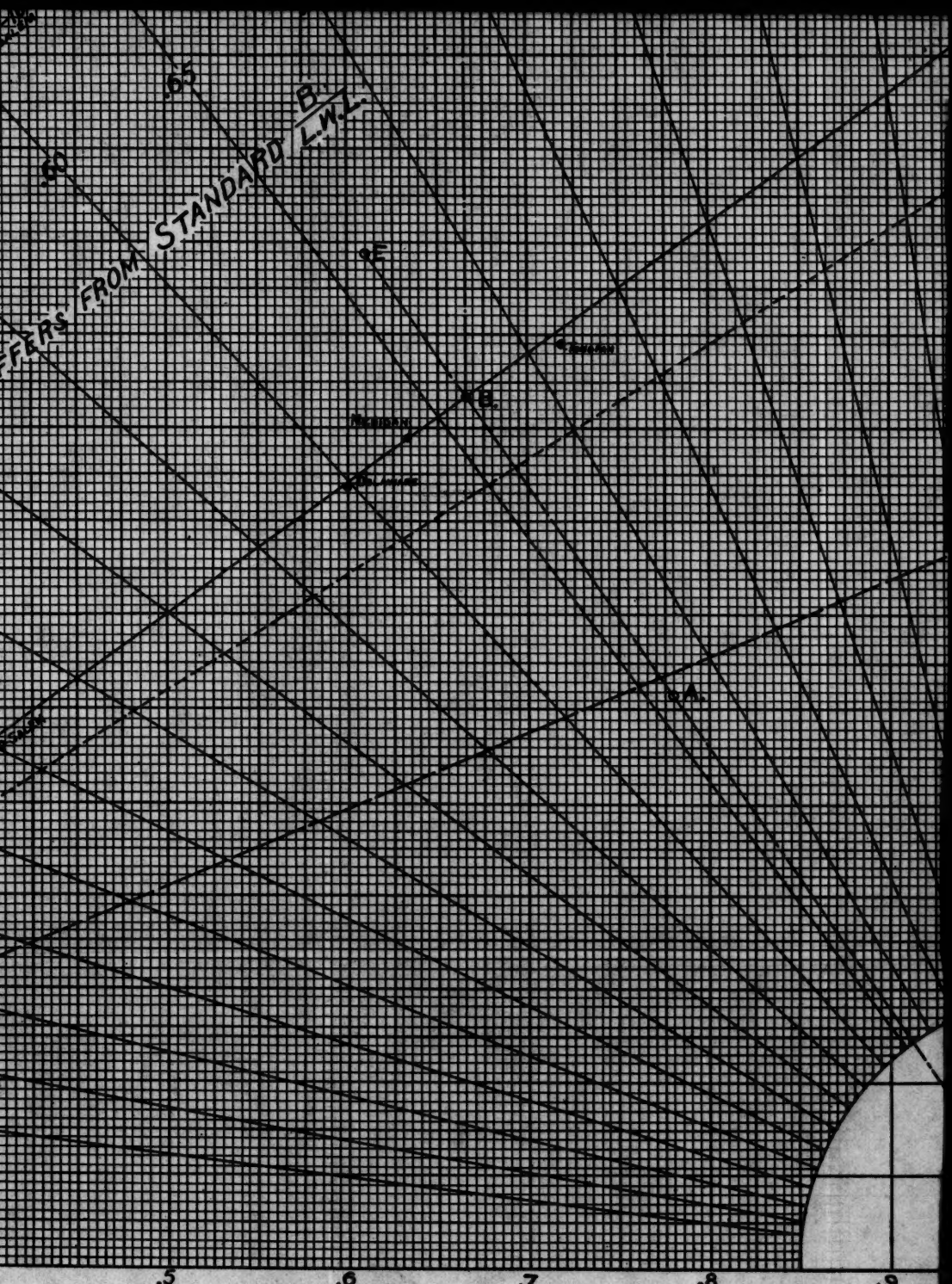
.60
.55
.50
.45
.40
.35
.30
.25
.20
.15

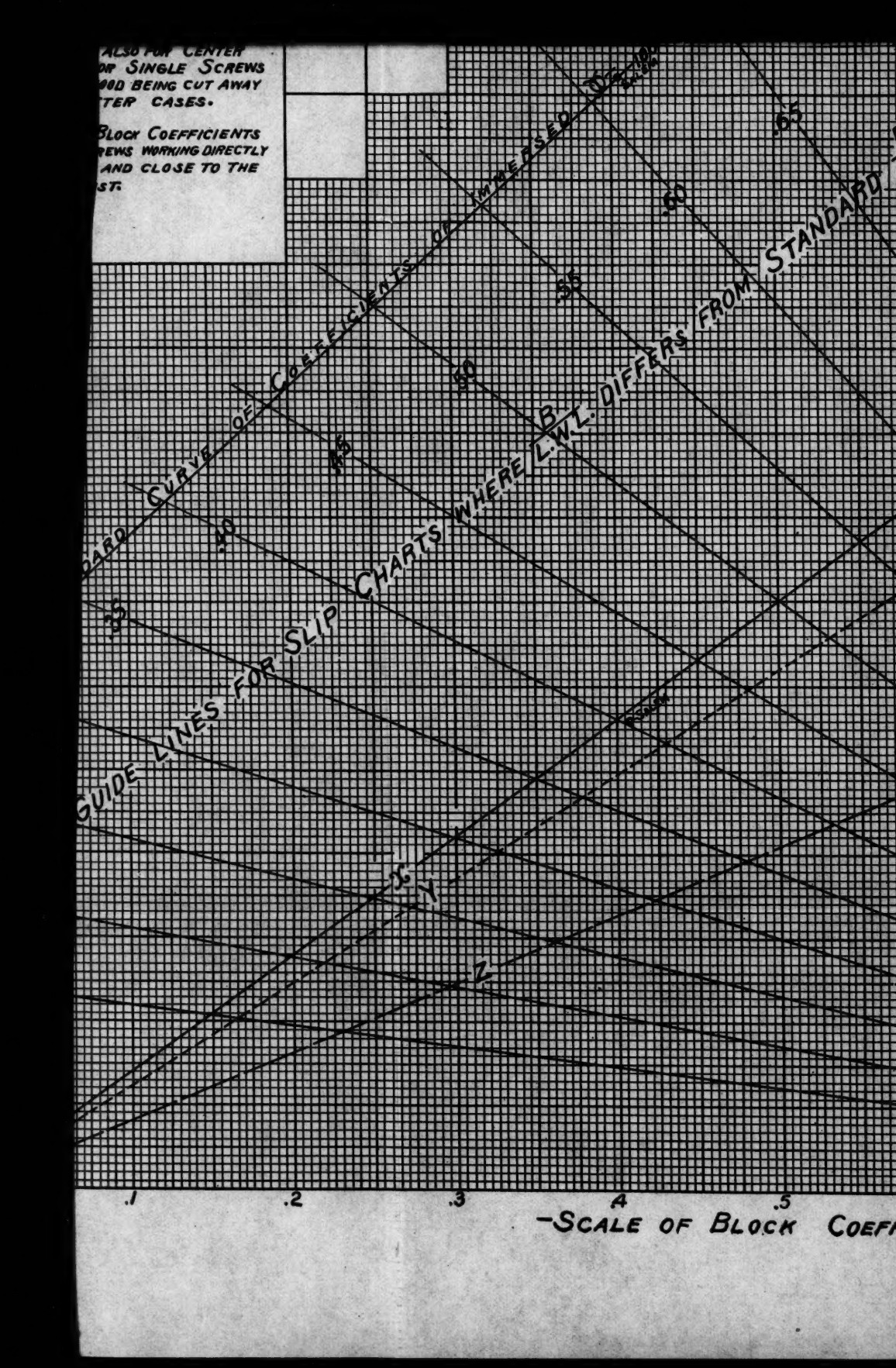
.1
.2
.3
.4

-SCALE OF GREATEST IMMERSED BEAM ÷ LENGTH ON LOAD WATER LINE = L.

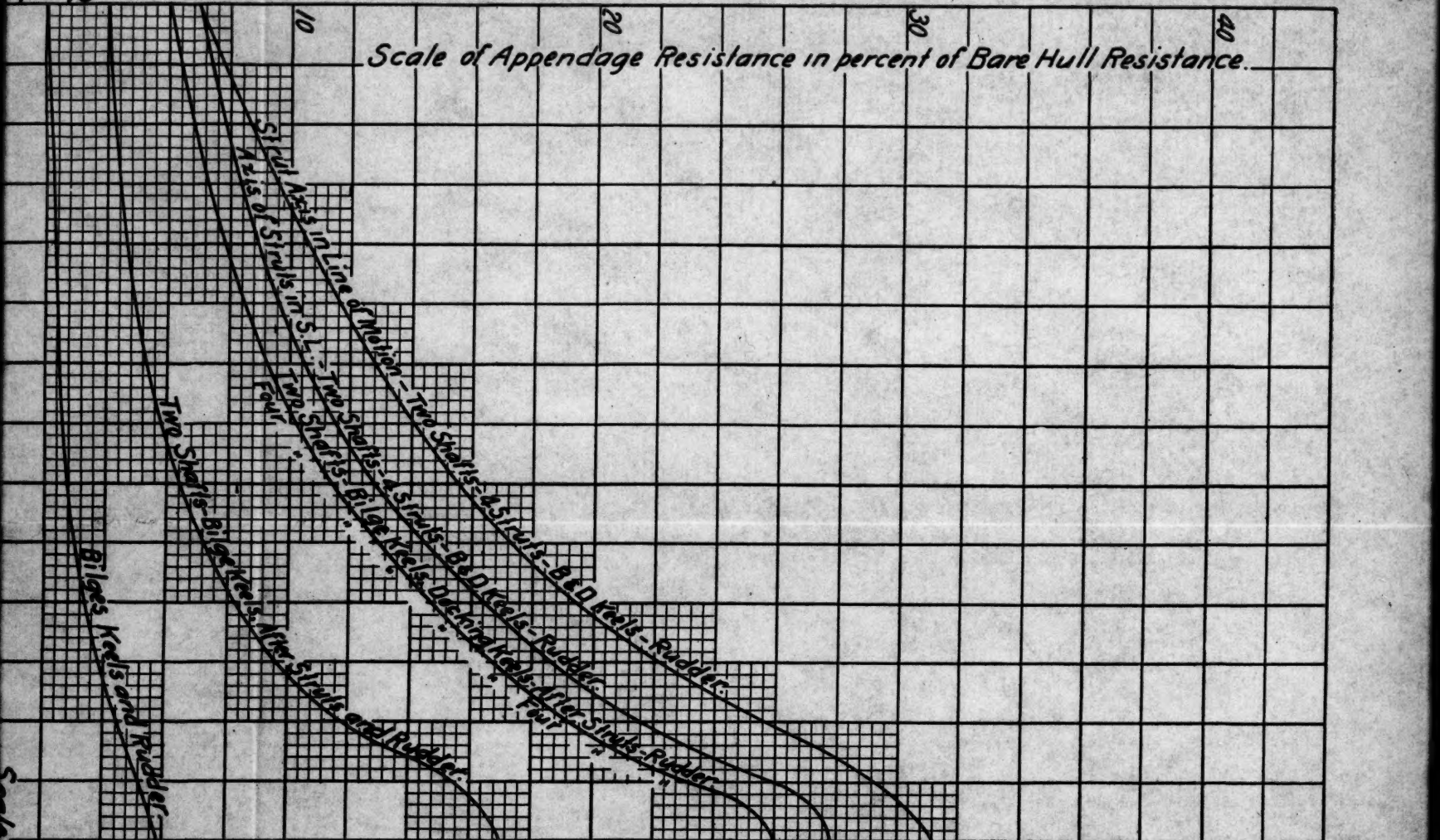
-SCALE OF

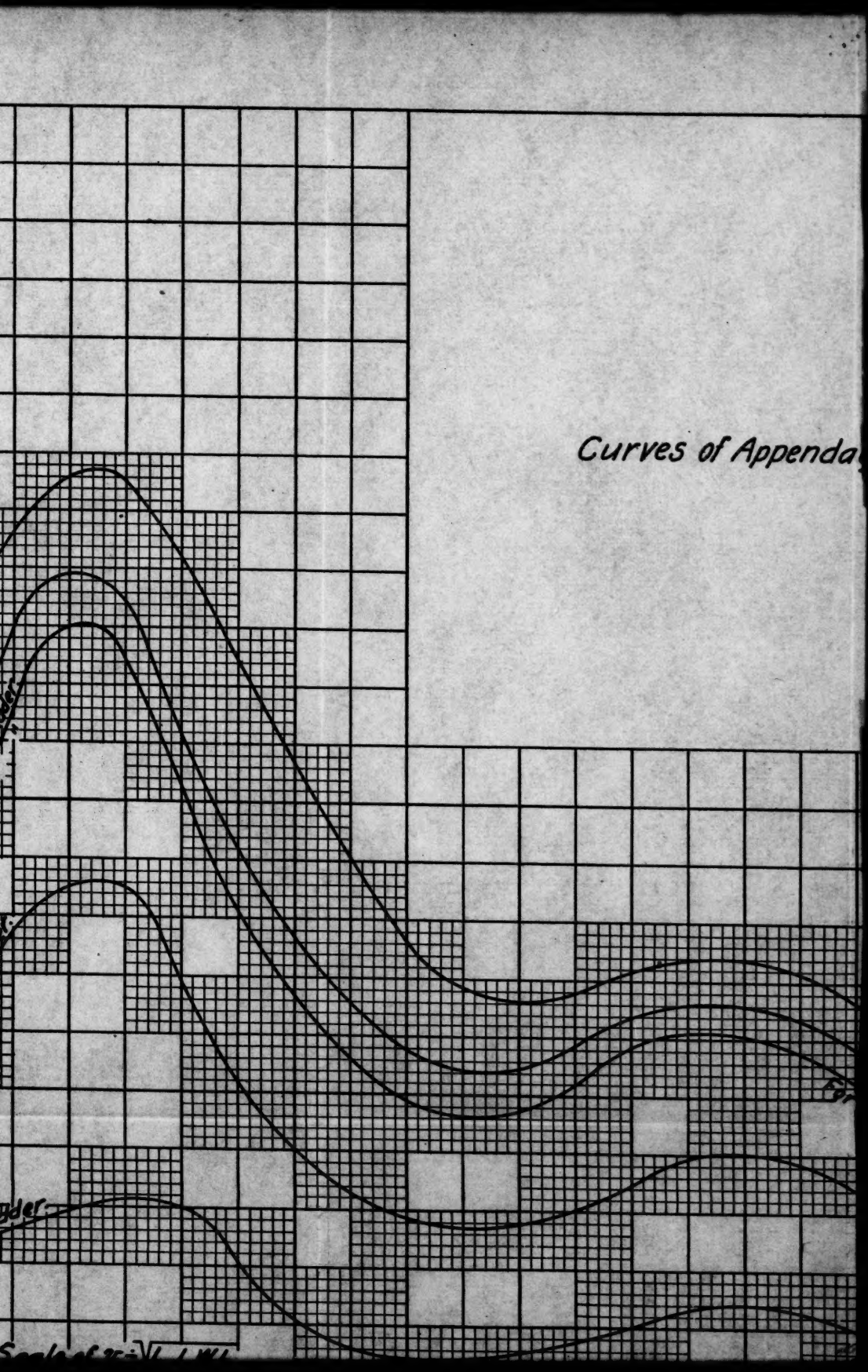
Sheet A.

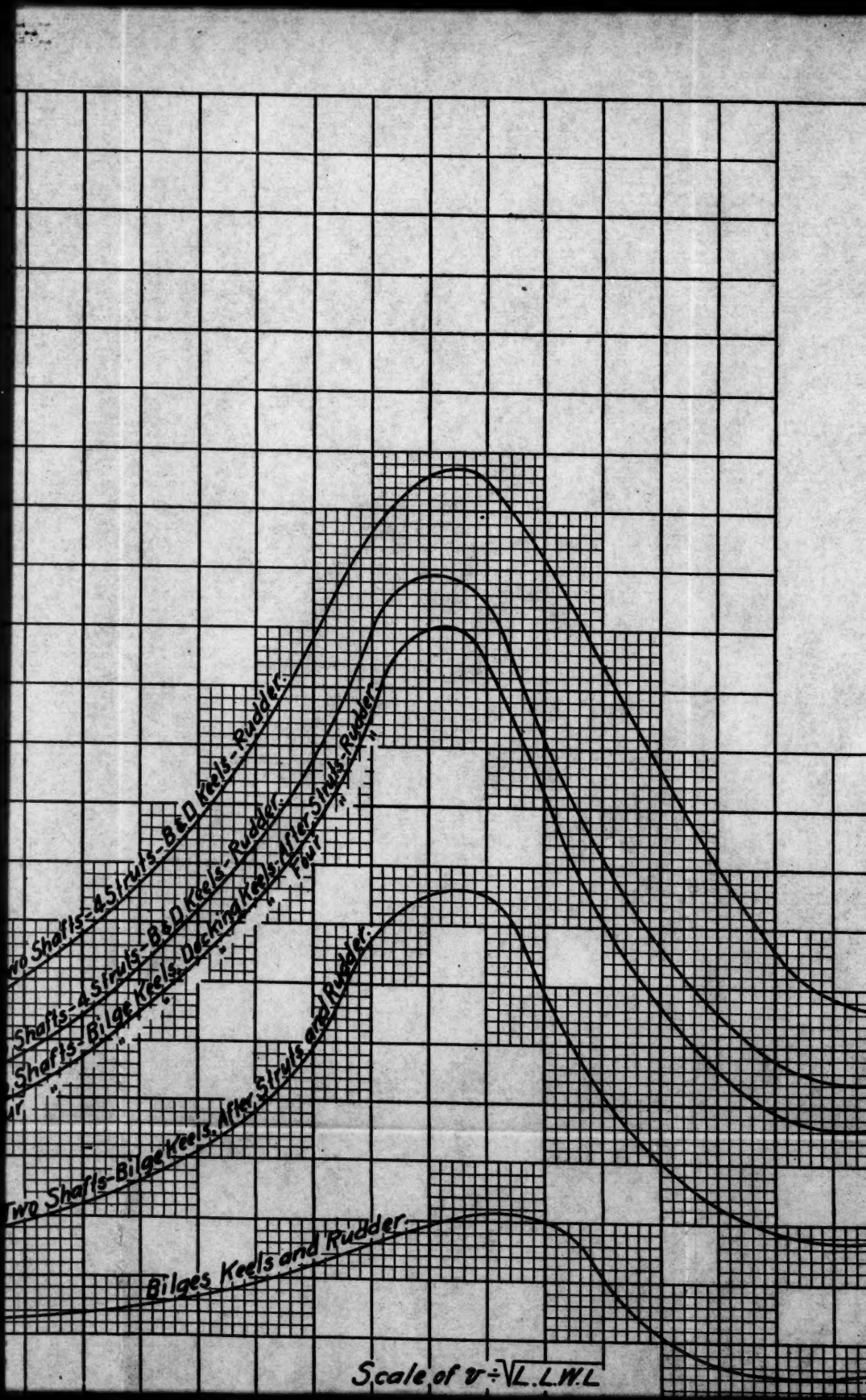

.65
.60
FFERS FROM STANDARD B/L.W.L.
.9E
.8B
.8A
.5
.6
.7
.8
.9
E OF BLOCK COEFFICIENTS—


ALSO FOR CENTER
OR SINGLE SCREWS
OOD BEING CUT AWAY
TER CASES.
BLOCK COEFFICIENTS
REWS WORKING DIRECTLY
AND CLOSE TO THE
ST.
.65
.60
.55
.50
.45
.40
.35
STANDARD CURVE OF COEFFICIENTS OF IMMERSED MIDSHIP SECTION
WHERE L.W.L. DIFFERS FROM STANDARD
GUIDE LINES FOR SLIP CHARTS
.1
.2
.3
.4
.5
SCALE OF BLOCK COEFF

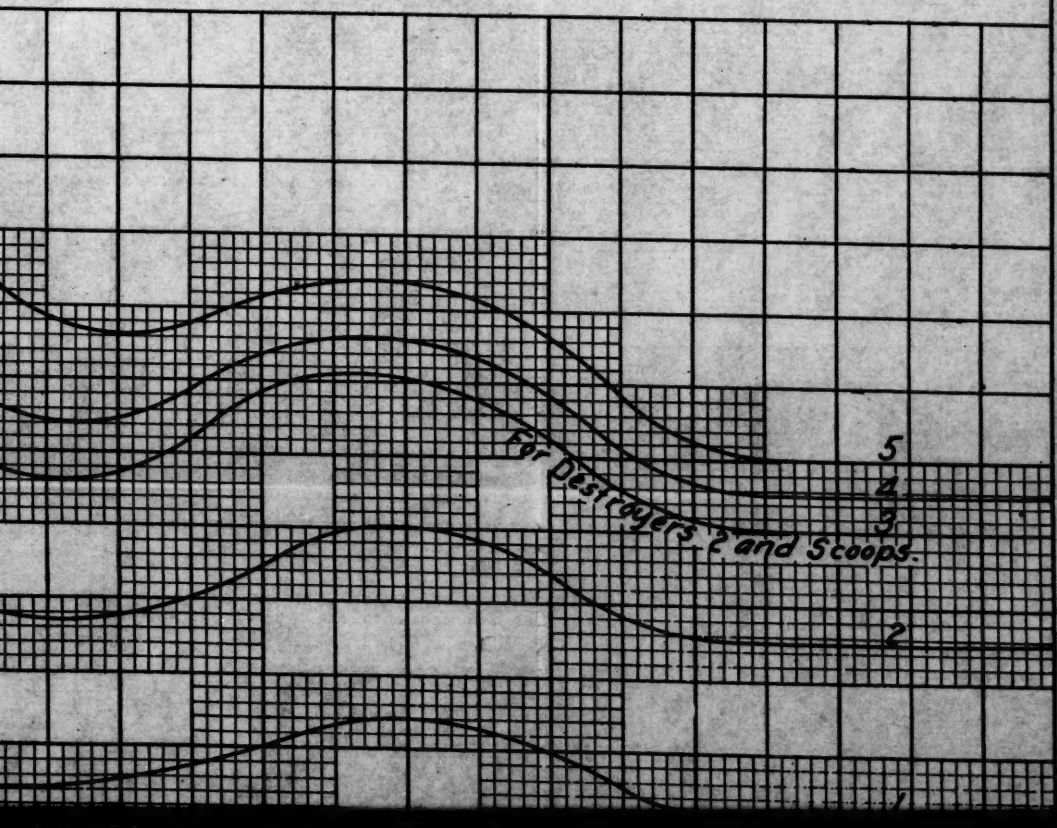
DARD B
L.W.L.
E
B
A
D
.6
.7
.8
.9
COEFFICIENTS—
1
.6
.5
.4
.3
.2
.1
0
-SCALE OF COEFFICIENT OF IMMERSED


Sheet-
10
20
30
40
Scale of Appendage Resistance in percent of Bare Hull Resistance.
Struts Axis in Line of Motion - Two Shafts - 4 Struts - B & O Keels - Rudder.
Axis of Struts in S.L. - Two Shafts - 4 Struts - B & O Keels - Rudder.
Two Shafts - Bilge Keels - Declined Keels - After Struts - Rudder.
Two Shafts - Bilge Keels - After Struts and Rudder.
Bilges Keels and Rudder.

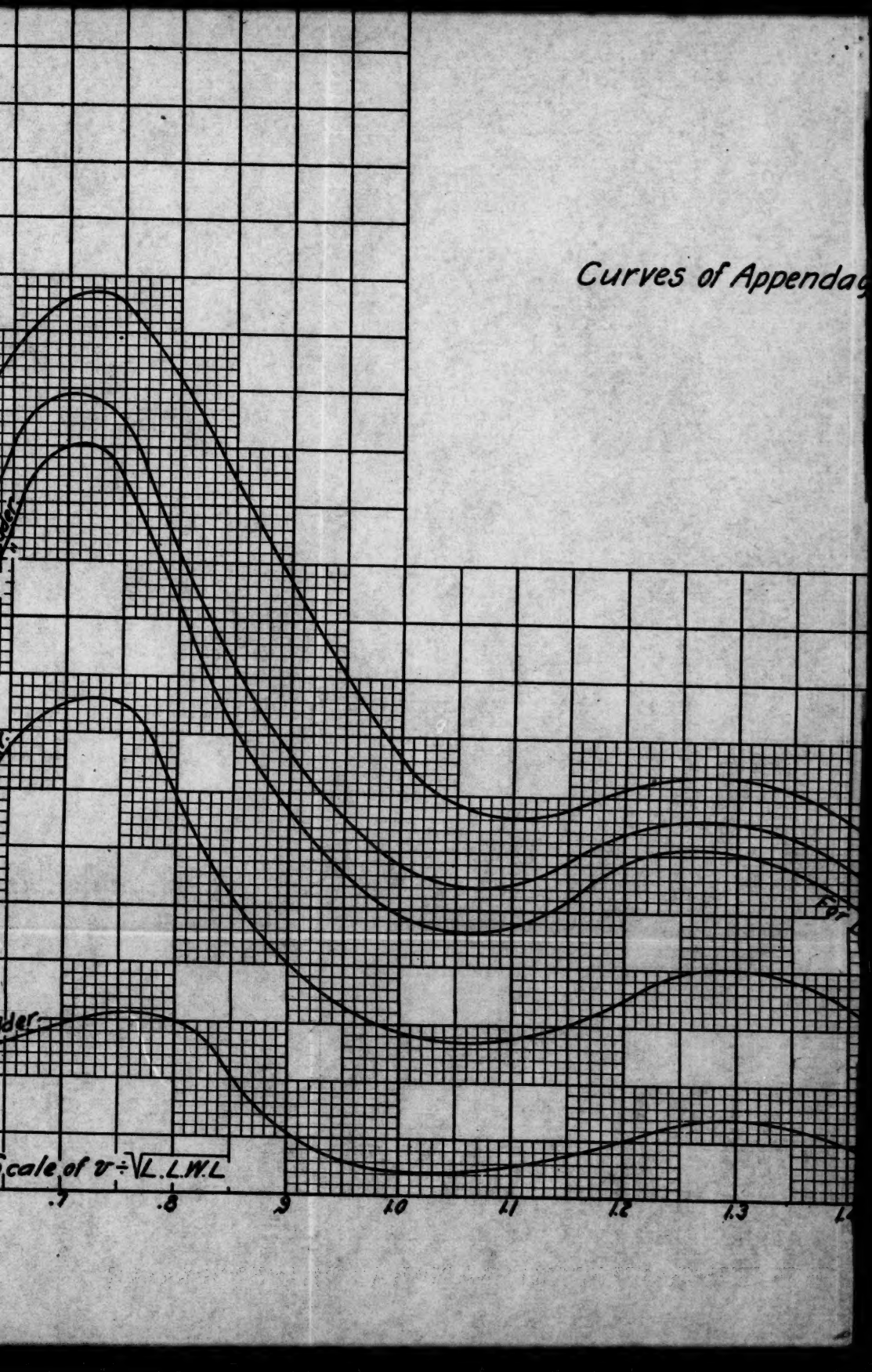

Curves of Appenda

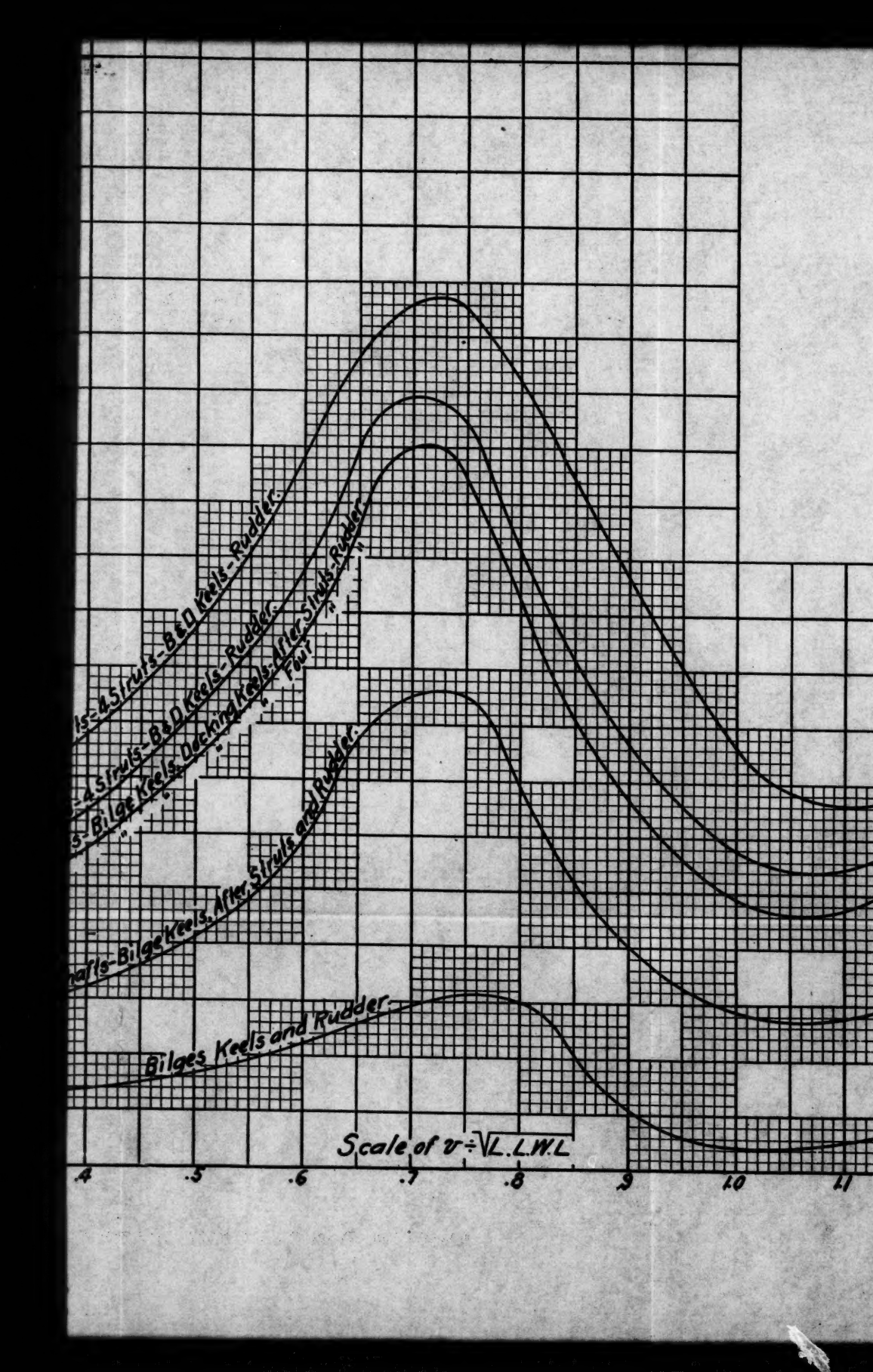

Two Shafts-4 Struts-B&D Keels-Rudders.
Shafts-4 Struts-B&D Keels-Rudder.
Shafts-Bilge Keels-Docking Keels-After Struts-Rudder.
Four
Two Shafts-Bilge Keels-After Struts and Rudder.
Bilges Keels and Rudder
Scale of $v \div \sqrt{L.L.W.L}$

Curves of Appendage Resistance.

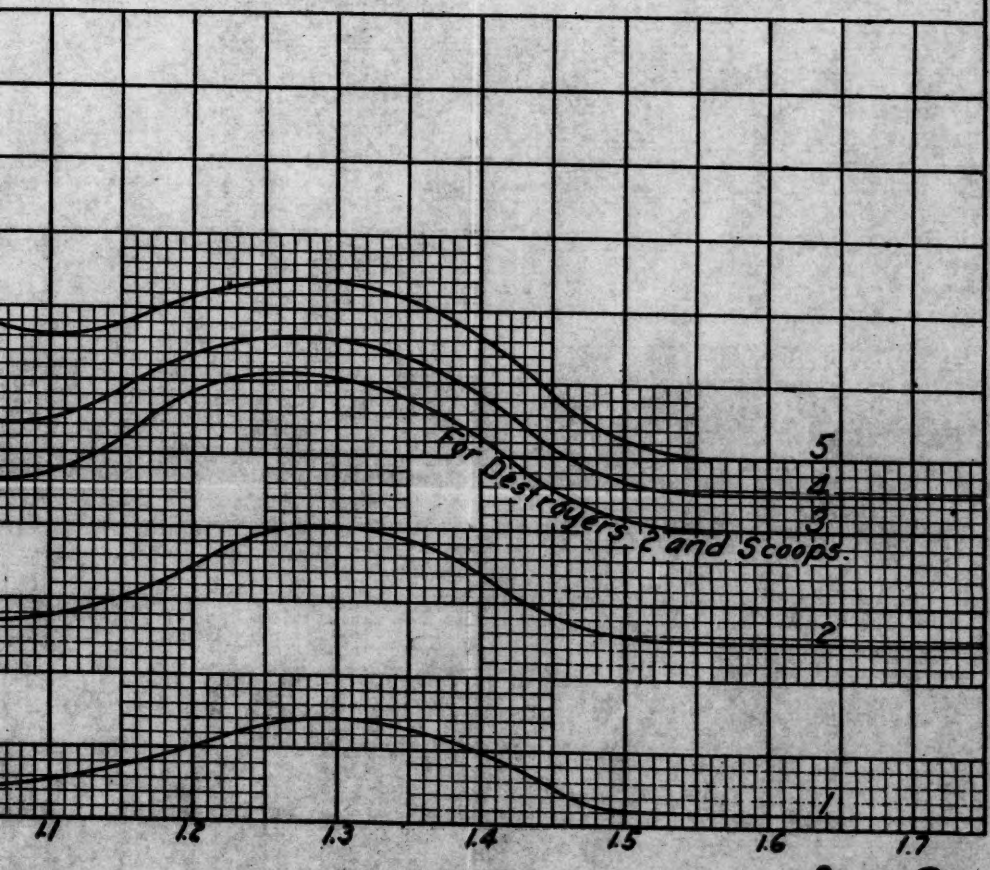


Sheet-B
0
10
20
30
40
Scale of Appendage Resistance in percent of Bare Hull Resistance
1
2
3
4
5
6
Scale
Struts in Line of Motion - Two Shafts - 4 Struts - B&D Keels - Rudders
Axis of Struts in S. L. - Two Shafts - 4 Struts - B&D Keels - Rudders
Two Shafts - Bilge Keels - Decking Keel - Four Struts - Rudders
Two Shafts - Bilge Keels - Four Struts and Rudders
Bilge Keels and Rudders


Curves of Appendag
Scale of $v \div \sqrt{L.L.W.L}$
.7
.8
.9
1.0
1.1
1.2
1.3


Bilges Keels and Rudder.
Bilges Keels. After Struts and Rudder.
Bilge Keels. Docking Keels. After Struts. Rudder.
4 Struts. B & O Keels. Rudder.
Four
Scale of $v \div \sqrt{L.L.W.L}$
.4
.5
.6
.7
.8
.9
1.0
1.1

Curves of Appendage Resistance.



Sheet B.

Vessel of ⊠₁

ⓐ Propeller located at Section ①

$A - C_2$ = Min. values of K.

$C_1 - C_2$ = Max. " " K.

Propellers located at Section ②

$C_1 - C_2$ = Values of K.

ⓐ

* Vessel of ⊠₂ Slip B.C. should not be corrected for difference from Standard ⊠ Coef. Propeller.

ⓑ Vessel of ⊠₂

$C - C_2$ = Max. values of K. for broad tip blades.

$C_3 - C_2$ = Min. values of K. for standard & narrow tip blades.

Vessel of ⊠₁ or ⊠₂ Single Screw.

Slip B.C. should be corrected for variation of ⊠ Coef. from Standard

$C - C$ = Min. values of K. for draft < 12 feet. {Screw deeply immersed.

ⓒ

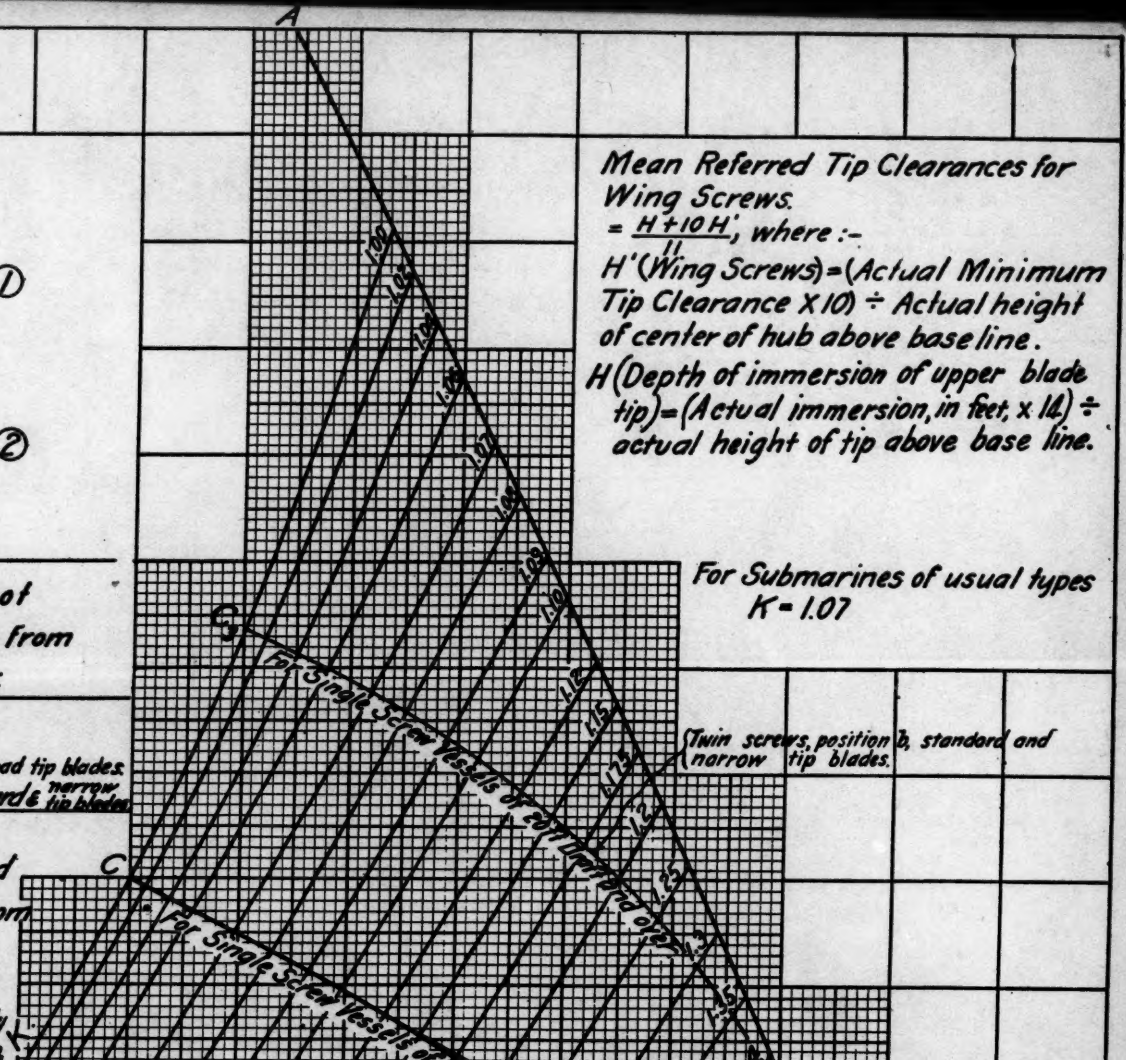
Mean Referred Tip Clearances for Wing Screws.

$= \frac{H + 10H'}{11}$, where :-

H'(Wing Screws) = (Actual Minimum Tip Clearance X 10) ÷ Actual height of center of hub above base line.

H(Depth of immersion of upper blade tip) = (Actual immersion, in feet, x 12) ÷ actual height of tip above base line.

For Submarines of usual types K = 1.07


A
C3
For Single Screw Vessels of Turbine type.
C
For Single Screw Vessels of Reciprocating type.
Twin screws, position ②, standard and narrow tip blades.

C - C = Min. values of K. for draft < 12 feet. {Screw deeply immersed.

$C_3 - C_2$ = Min. values of K for vessel with draft greater than 20 ft.

$C - C_2$ = Max. values of K.

* Applies to Slip B.C. > .55

Curves of K

Vessels of standard Section, Position ②

Vessels of less than standard draft and under

Twin screws, position b, broad tip blades.

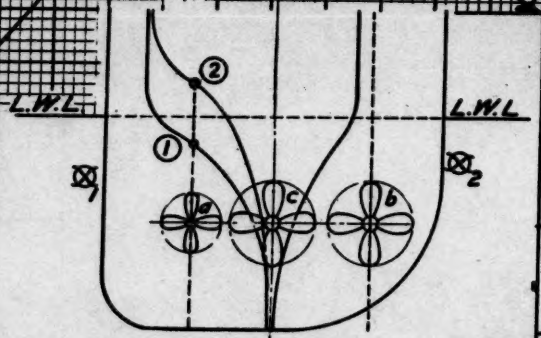
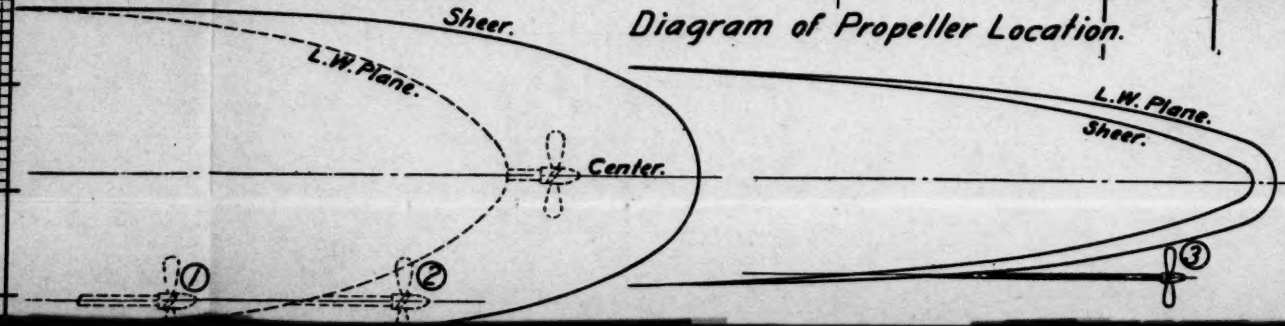


Diagram of Propeller Location.



$C_1 - C_2$ = Max. " - K.

Propellers located at Section ②

$C_1 - C_2$ = Values of K.

①

Vessel of ⊠₂ Slip B.C. should not be corrected for difference from Standard ⊠ Coef. Propeller.

② Vessel of ⊠₂

$C - C_2$ = Max. values of K. for broad tip blades.

$C_3 - C_2$ = Min. values of K. for standard & narrow tip blades.

Vessel of ⊠₁ or ⊠₂ Single Screw.

Slip B.C. should be corrected for variation of ⊠ Coef. from Standard

$C - C$ = Min. values of K. for draft < 12 feet. (Screw deeply immersed.

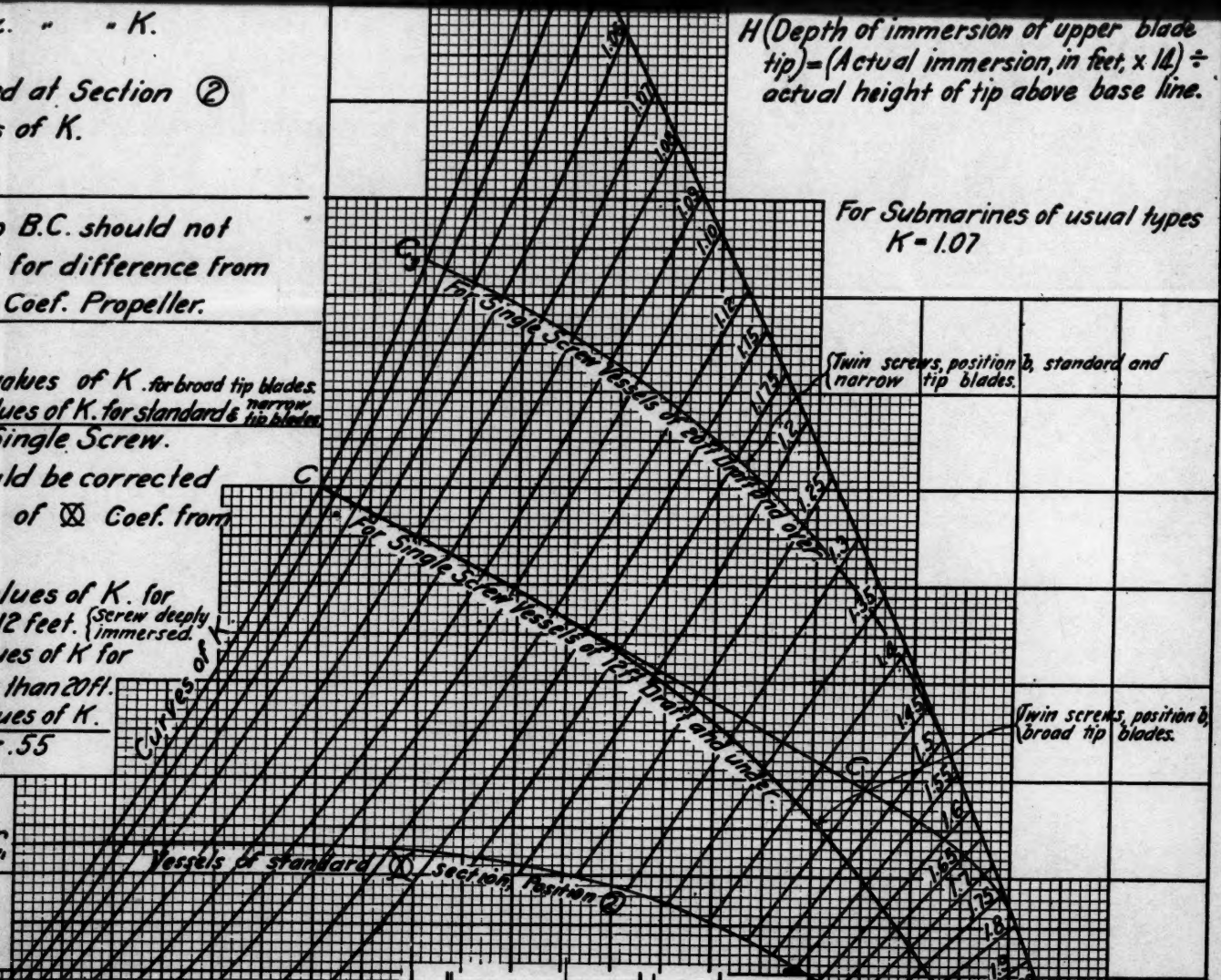
③ $C_3 - C_2$ = Min. values of K for vessel with draft greater than 20 ft.

$C - C_2$ = Max. values of K.

* Applies to Slip B.C. > .55

H (Depth of immersion of upper blade tip) = (Actual immersion, in feet, x 14) ÷ actual height of tip above base line.

For Submarines of usual types K = 1.07



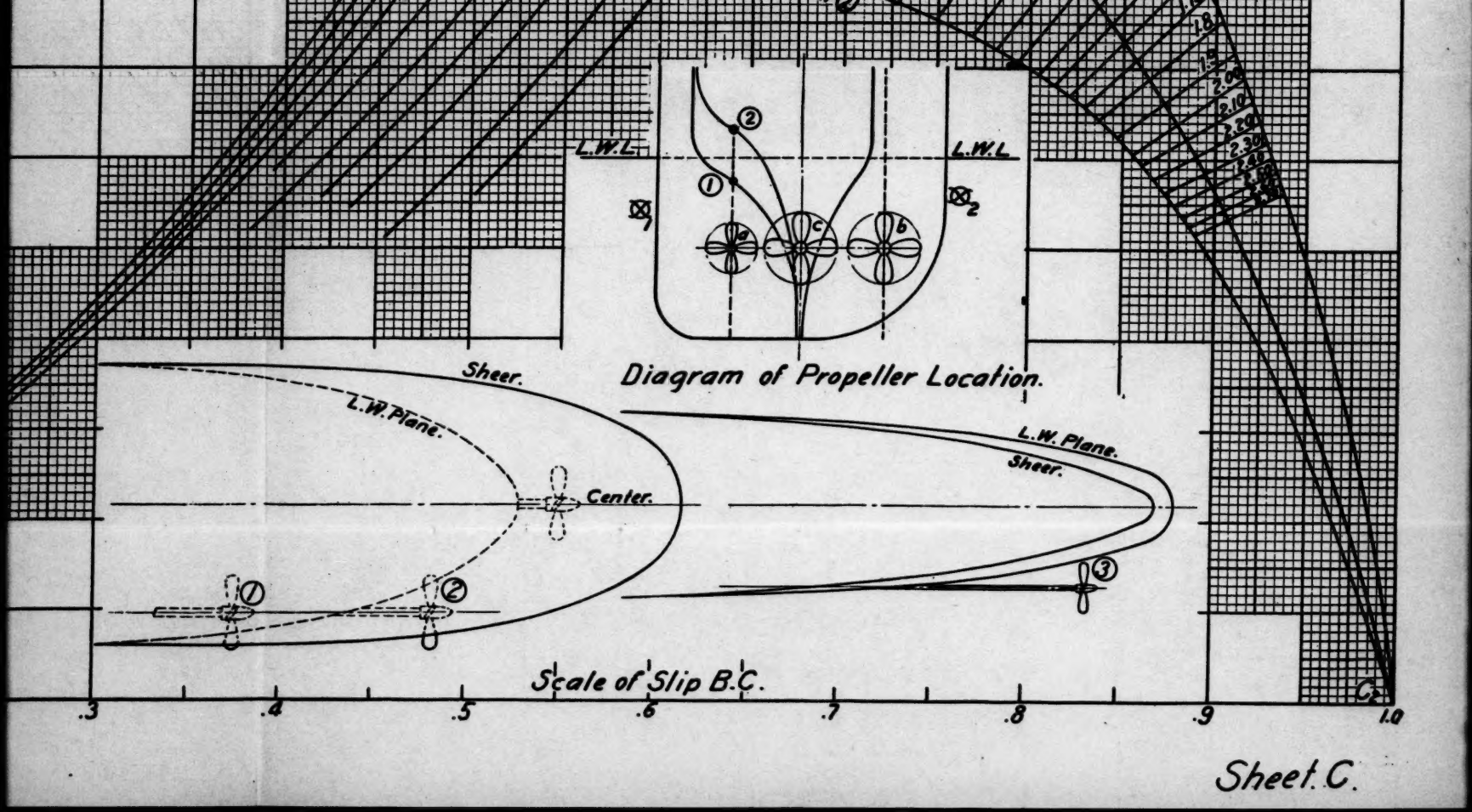


Diagram of Propeller Location.

Sheet C.

Vessel of ⊠₁

ⓐ Propeller located at Section ①

$A - C_2$ = Min. values of K.

$C_1 - C_2$ = Max. " " K.

4 Propellers located at Section ②

$C_1 - C_2$ = Values of K.

ⓐ

* Vessel of ⊠₂ Slip B.C. should not be corrected for difference from Standard ⊠ Coef. Propeller.

ⓑ Vessel of ⊠₂

$C - C_2$ = Max. values of K. for broad tip blades.

$C_2 - C_2$ = Min. values of K. for standard & narrow tip blades.

Vessel of ⊠₁ or ⊠₂ Single Screw.

3 Slip B.C. should be corrected for variation of ⊠ Coef. from Standard

ⓒ $C - C$ = Min. values of K. for draft < 12 feet. {Screw deeply immersed.

$C_1 - C_2$ = Min. values of K for

Mean Referred Tip Clea
Wing Screws.
= $\frac{H + 10H'}{11}$, where :-
H'(Wing Screws)=(Actua
Tip Clearance X10) ÷ Ac
of center of hub above b
H(Depth of immersion of
tip)=(Actual immersion,
actual height of tip abo

For Submarines o
K = 1.07

C₂ For Single Screw Vessels of Full Forms

{Twin screws, position 2, narrow tip blades.

C For Single Screw Vessels of

1.00 1.05 1.10 1.15 1.20 1.25 1.30 1.35 1.40 1.45 1.50 1.55 1.60 1.65 1.70 1.75 1.80 1.85 1.90 1.95 2.00

Scale of Mean T.C.

C - C = Min. values of K. for draft < 12 feet. {Screw deeply immersed.

$C_3 - C_2$ = Min. values of K for vessel with draft greater than 20 ft.

$C - C_2$ = Max. values of K.

* Applies to Slip B.C. > .55

Scale of

Vessels of standard Section, Position ①

Vessels of 12½ draft and under.

L.W.L.

L.W.L.

Diagram of Propeller Location.

Sheer.

L.W. Plane.

Center.

L.W. Plane.

Sheer.

$C_1 - C_2$ = Max. " " = K.

4 Propellers located at Section ②

$C_1 - C_2$ = Values of K.

ⓐ

* Vessel of ⊠₂ Slip B.C. should not be corrected for difference from Standard ⊠ Coef. Propeller.

ⓑ Vessel of ⊠₂

$C - C_2$ = Max. values of K. for broad tip blades.

$C_3 - C_2$ = Min. values of K. for standard & narrow tip blades.

Vessel of ⊠₁ or ⊠₂ Single Screw.

3 Slip B.C. should be corrected for variation of ⊠ Coef. from Standard

ⓒ $C - C$ = Min. values of K. for draft < 12 feet. {screw deeply immersed.

$C_3 - C_2$ = Min. values of K for vessel with draft greater than 20 ft.

$C - C_2$ = Max. values of K.

* Applies to Slip B.C. > .55

Scale of Mean T.C.

2

C_1

Curves of K

Vessels of standard ⊠ Section Position ②

C_3 For Single Screw Vessels of 20' Draft and over

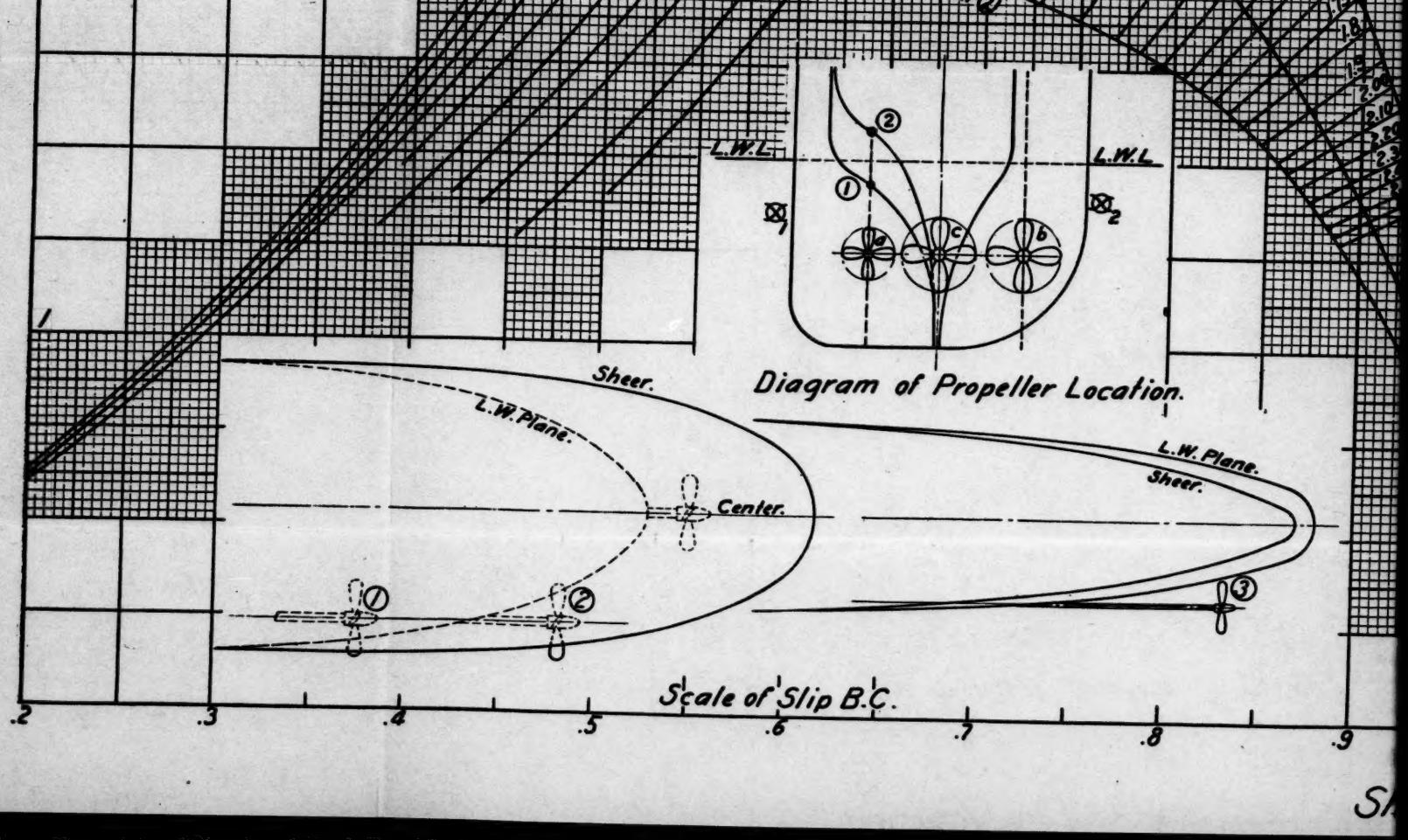
C For Single Screw Vessels of 12' Draft and under

(Twin screws, position b, narrow tip blades.

(Twin ... bro...

H (Depth of immersion of tip) = (Actual immersion ... actual height of tip abo...

For Submarines o...
K = 1.07


L.W.L
L.W.L
Diagram of Propeller Location.
Sheer.
L.W. Plane.
Center.
L.W. Plane.
Sheer.
Scale of Slip B.C.
.2
.3
.4
.5
.6
.7
.8
.9

Propeller Design Curves.

$IHP_d = IHP \div 10^2$

$D = \sqrt{\frac{291.8 \times IHP.}{I.T_0 \times P \times R}}$ (3 Bladed Propellers.)

$D = \sqrt{\frac{291.8 \times IHP \times .865}{I.T_0 \times P.\times R.}}$ (4 " ")

$D = \sqrt{\frac{291.8 \times IHP}{.75 \times I.T_0 \times P \times R.}}$ (2 " ")

P.A. ÷ D.A. = Projected Area Ratio of 3 Bladed Propeller.
= 3/4 " " " " 4 " "
= 3/2 " " " " 2 " "

P.C. = Percent Propulsive Coefficient corresponding to actual Projected Area Ratio.

Curve of P.C. and P.A. ÷ D.A.

Curve of $\frac{P}{D}$ and $\frac{V_a}{nD}$

+1.8
+1.7
+1.6
+1.5
+1.4
+1.3
+1.2
+1.1
+1.0

90
85
80
75
70
65
60
55
52

Curves of I.-S. for different values of P.F.D.A. (and of Slip Block Coefficient)
Scale of Z.
Scale of I.-S.
Scale of e.h.p. ÷ E.H.P.
Curves of I.-S. and P.F.D.A.
Curves of I.-S. and Slip Block Coefficient
Curves of I.-S. and Slip
Curves of I.-S. and Slip
Curves of I.-S. and Slip

$$D = \sqrt{\frac{291.8 \times IHP \times .865}{I.T._0 \times P \times R.}} \quad (4 \text{ " } \text{ " })$$

$$D = \sqrt{\frac{291.8 \times IHP}{.75 \times I.T._0 \times P \times R.}} \quad (2 \text{ " } \text{ " })$$

P.A. ÷ D.A. = Projected Area Ratio of 3 Bladed Propeller.
= 3/4 " " " " 4 " "
= 3/2 " " " " 2 " "

P.C. = Percent Propulsive Coefficient corresponding to actual Projected Area Ratio.

Curve of P.C. and P.A. ÷ D.A.

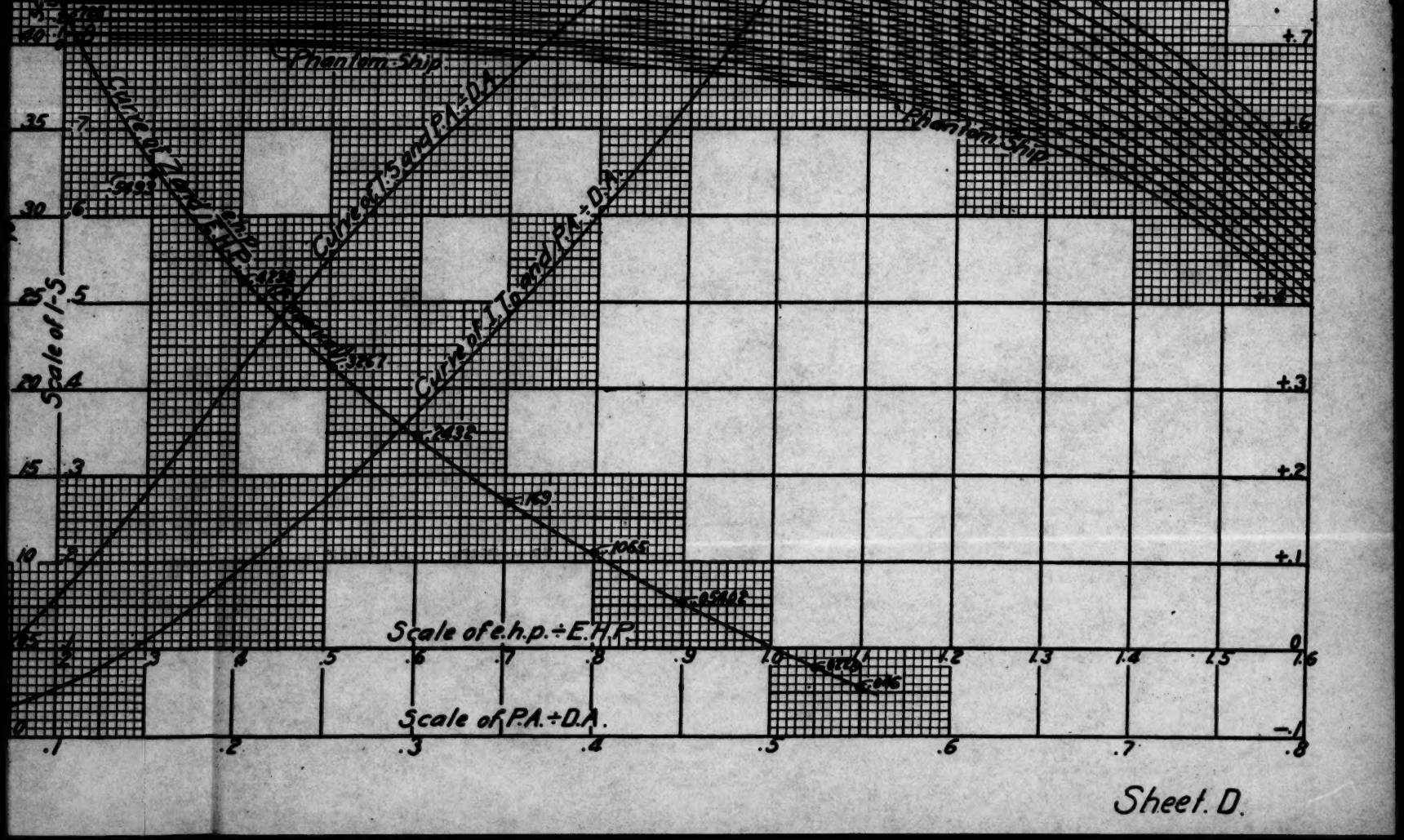
Curves of I-S for different values of P.A. ÷ D.A.

Lands of Slip (Block Coefficient)

Scale of P.C. %

Scale of Z.

Phantom Ship


Phantom Ship
Phantom Ship
Curve of Load P.A. ÷ D.A.
Curve of Load P.A. ÷ D.A.
Curve of Load P.A. ÷ D.A.
Scale of 1-5
Scale of e.h.p. ÷ E.H.P.
Scale of P.A. ÷ D.A.
Sheet. D.

Propeller Design Curves.

$IHP_d = IHP \div 10^z$

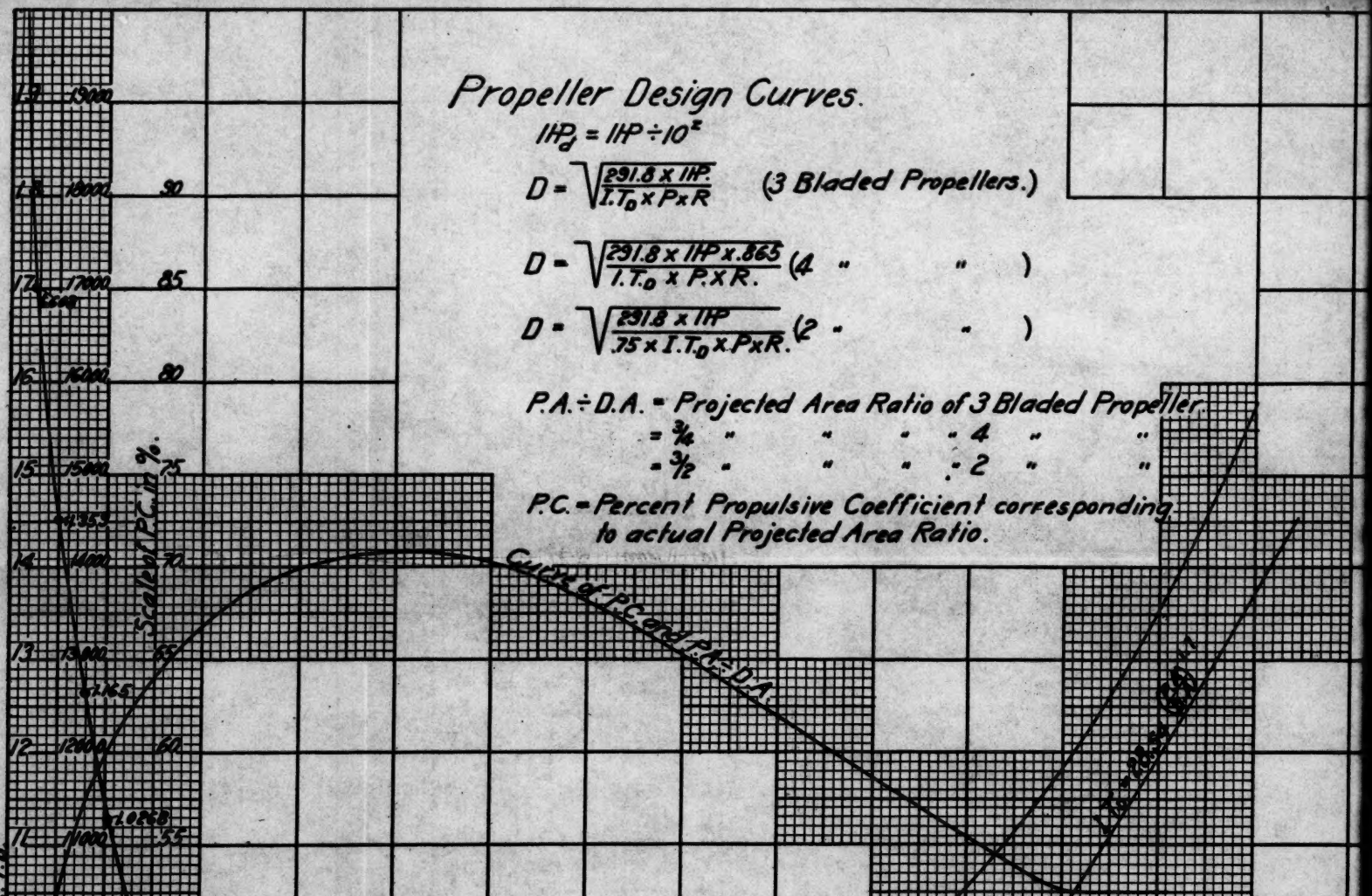
$D = \sqrt{\frac{291.8 \times IHP.}{I.T_D \times P \times R}}$ (3 Bladed Propellers.)

$D = \sqrt{\frac{291.8 \times IHP \times .865}{I.T_D \times P. \times R.}}$ (4 " ")

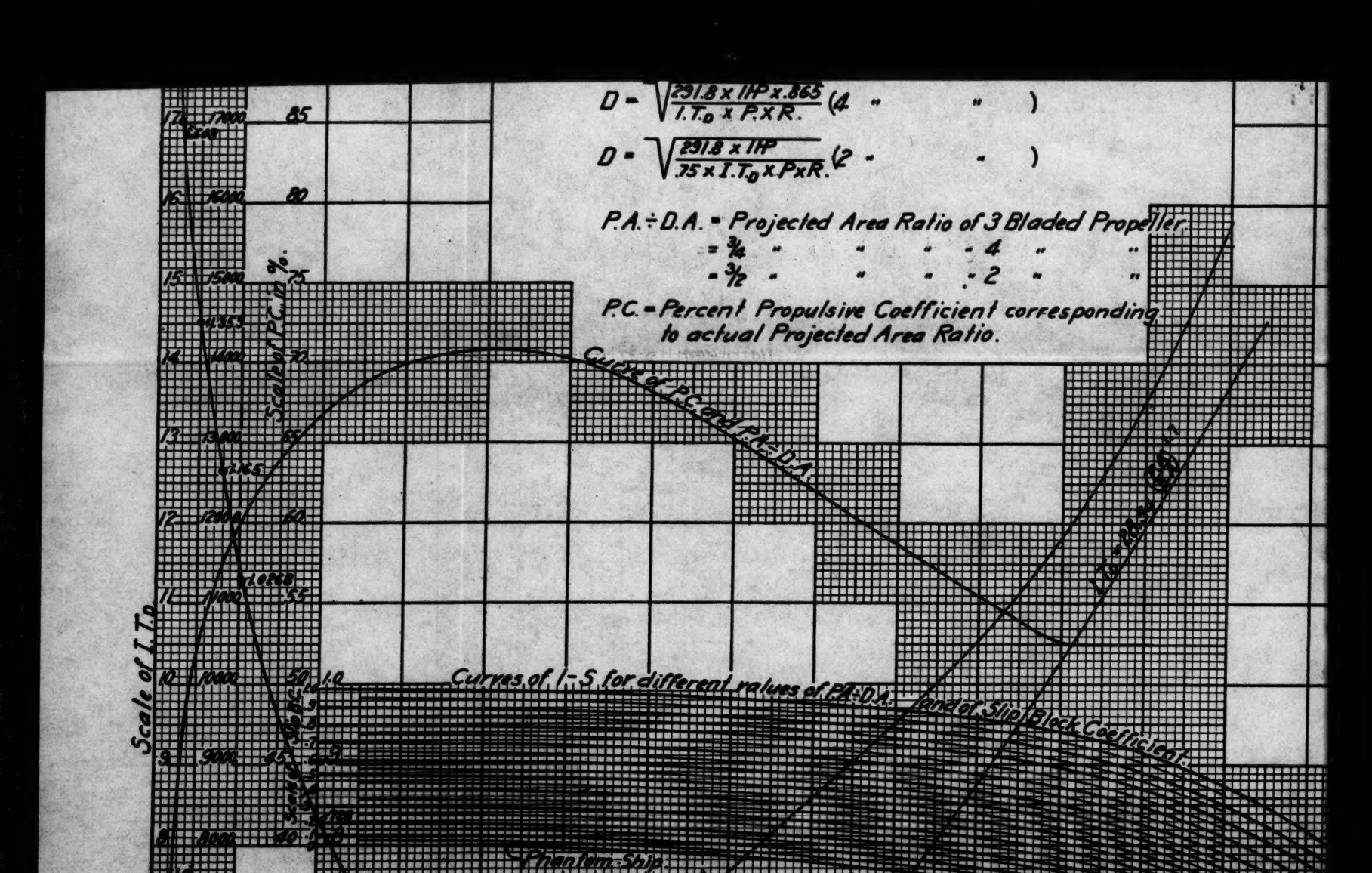
$D = \sqrt{\frac{291.8 \times IHP}{.75 \times I.T_D \times P \times R.}}$ (2 " ")

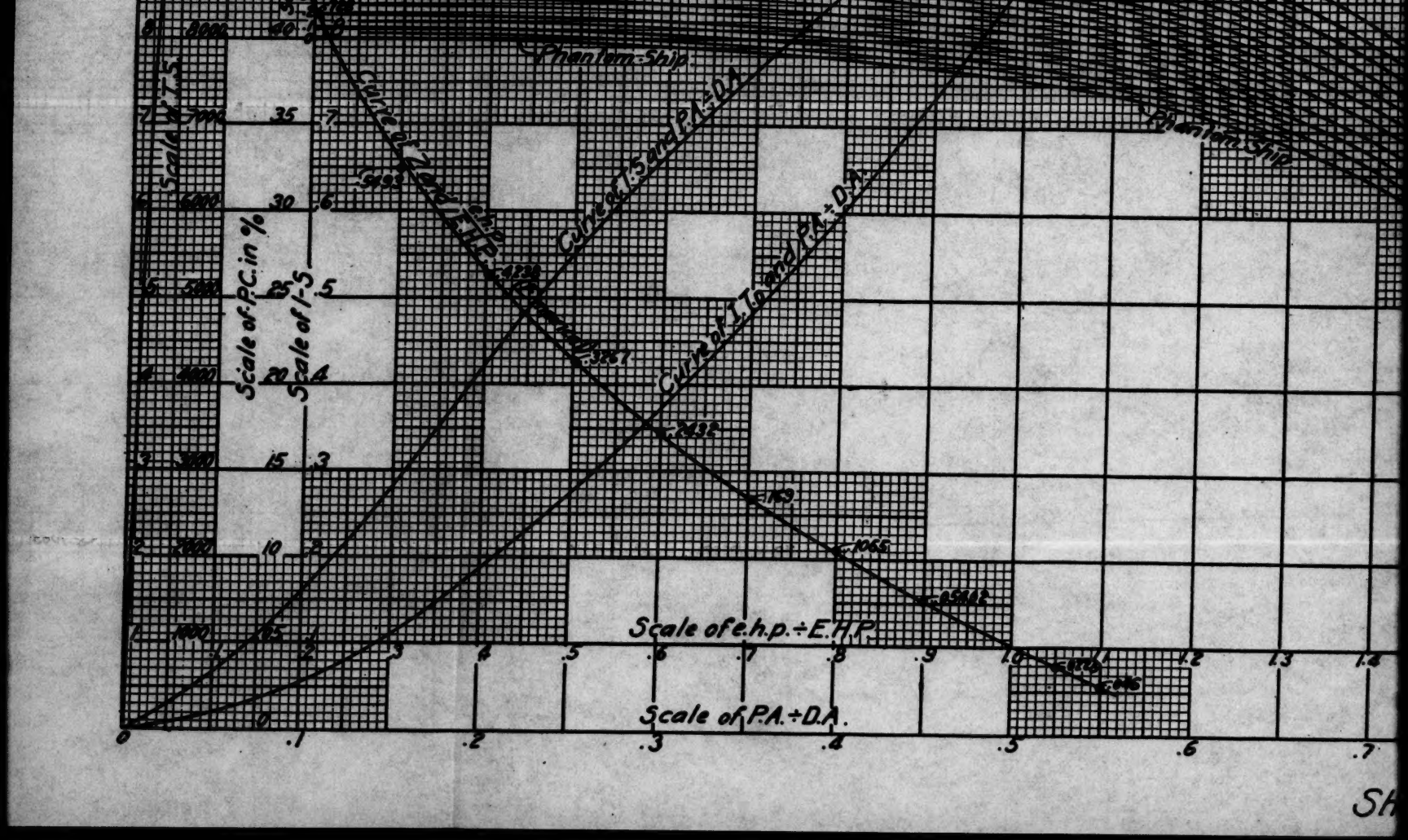
P.A. ÷ D.A. = Projected Area Ratio of 3 Bladed Propeller.
= 3/4 " " " " 4 " "
= 3/2 " " " " 2 " "

P.C. = Percent Propulsive Coefficient corresponding to actual Projected Area Ratio.

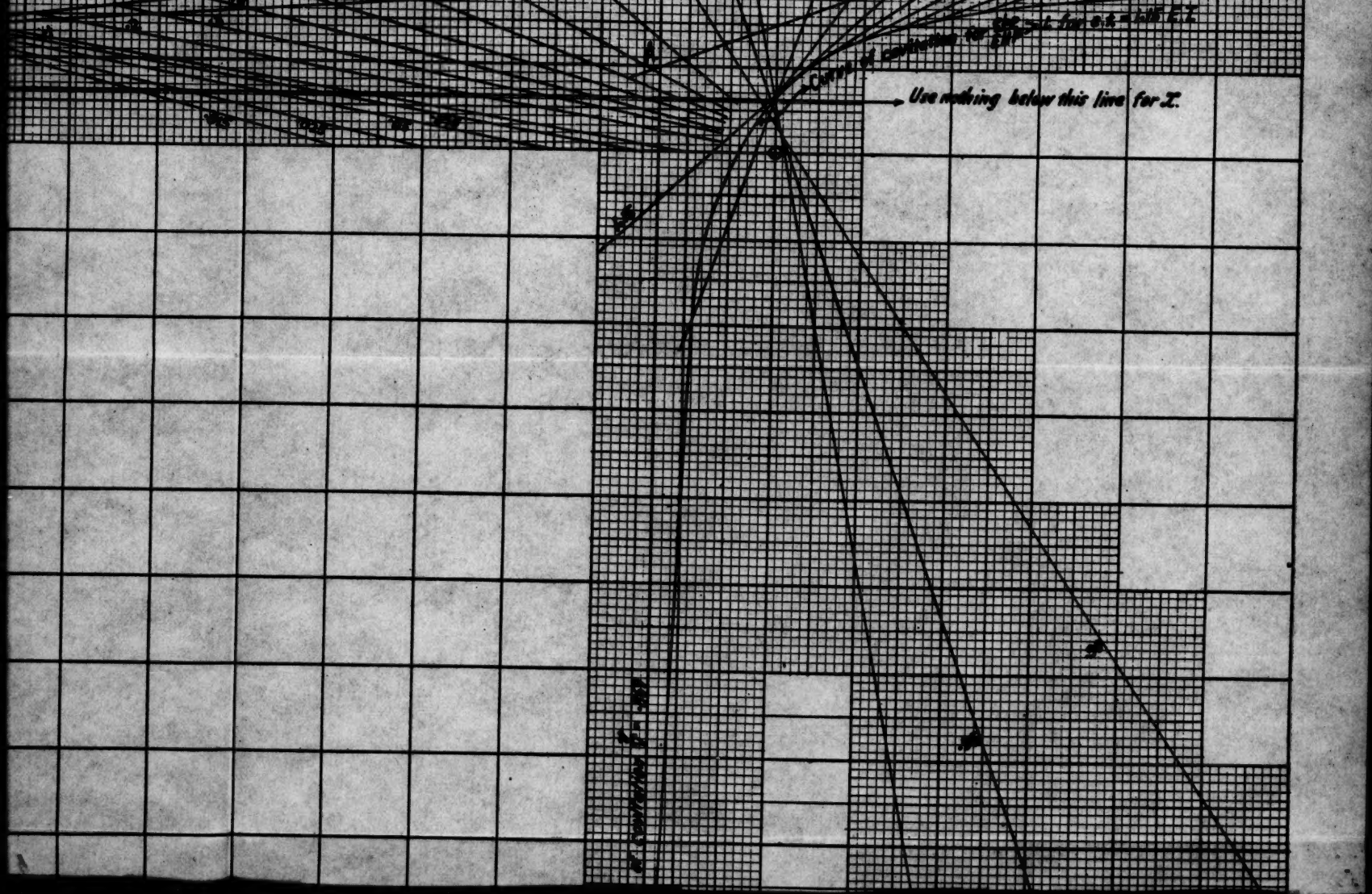


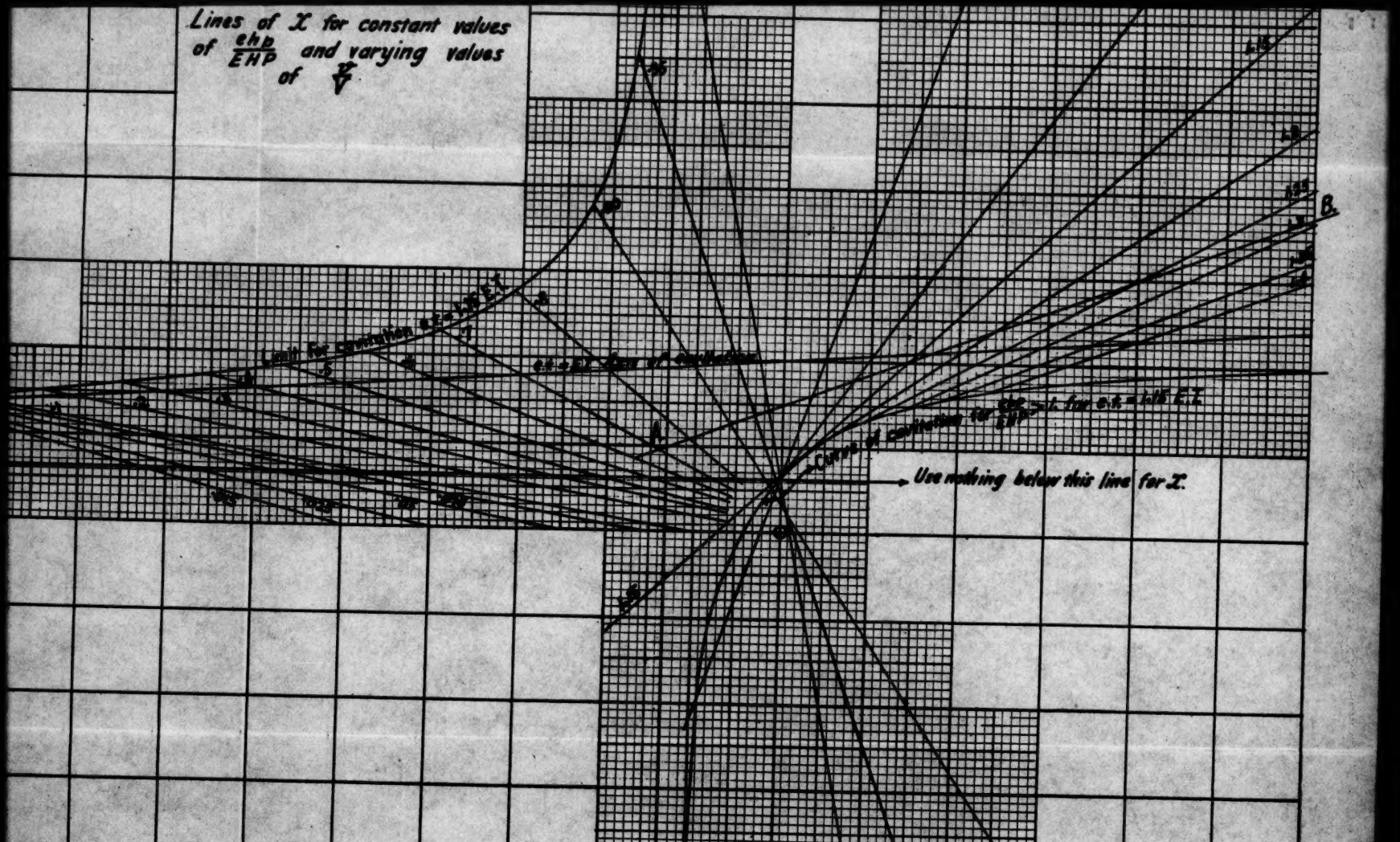
Curves of I-S for different values of E.H.P.
Scale of I.T.P.
Scale of I-S
Scale of P.C. in %
Scale of e.h.p.÷E.H.P.


$D = \sqrt{\frac{291.8 \times IHP \times .865}{I.T_0 \times P \times R.}}$ (4 " ")
$D = \sqrt{\frac{291.8 \times IHP}{.75 \times I.T_0 \times P \times R.}}$ (2 " ")
P.A. ÷ D.A. = Projected Area Ratio of 3 Bladed Propeller.
= 3/4 " " " " 4 " "
= 3/2 " " " " 2 " "
P.C. = Percent Propulsive Coefficient corresponding to actual Projected Area Ratio.
Curve of P.C. and P.A. ÷ D.A.
Curves of I. S for different values of P.A. ÷ D.A.
Scale of I.T.D.
Scale of P.C. %
Scale of I.S.
Phantom Ship
17 17000 85
16 16000 80
15 15000 75
14 14000 70
13 13000 65
12 12000 60
11 11000 55
10 10000 50
9 9000 45
8 8000 40
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
1.353
1.165
1.0283
Land of Slip Block Coefficient.

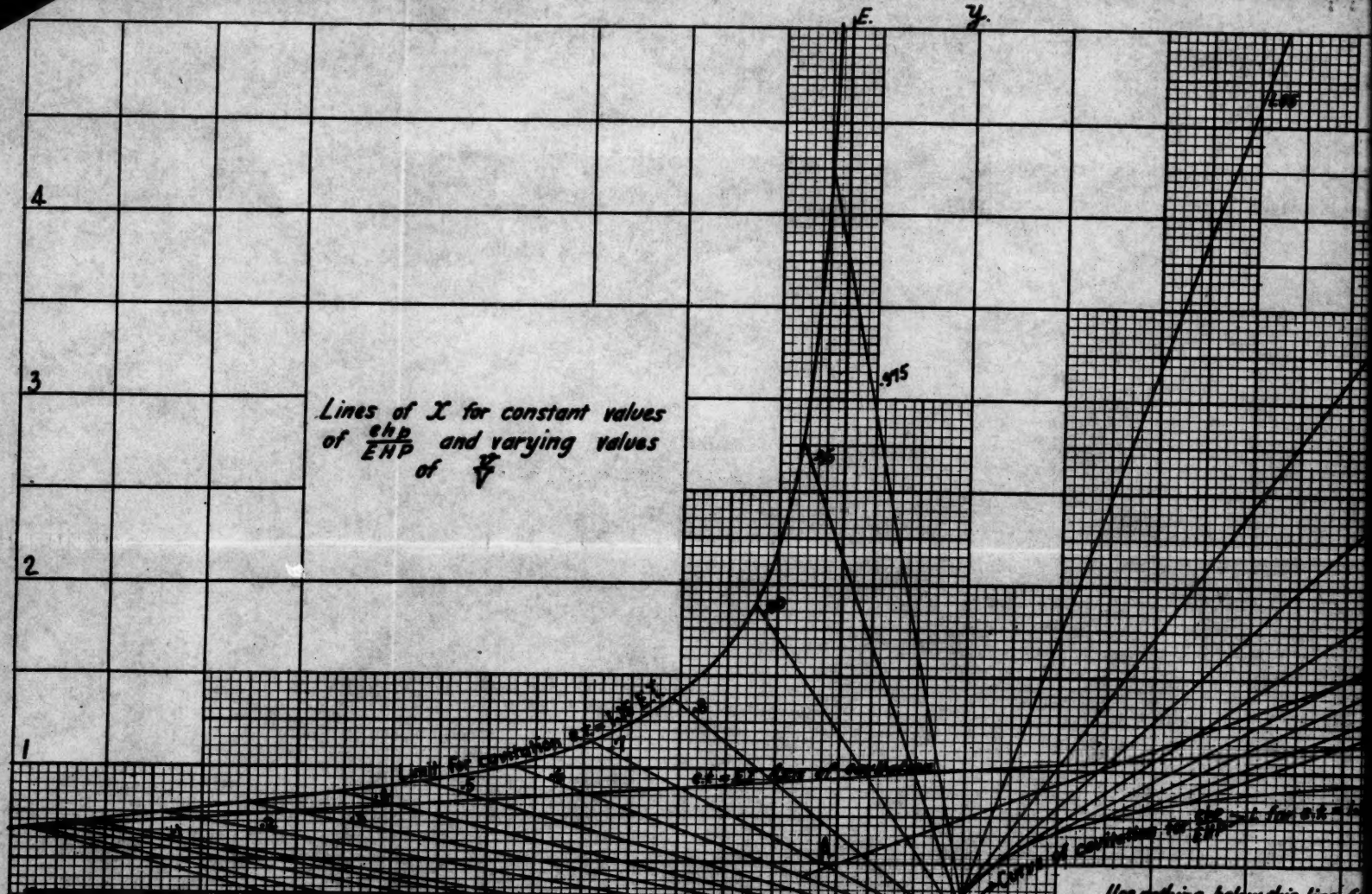

Phantom Ship
Curve of I.5 and P.A.÷D.A.
Curve of I. I and P.A.÷D.A.
Scale of P.C. in %
Scale of I-S
Scale of e.h.p.÷E.H.P.
Scale of P.A.÷D.A.

Lines of χ for constant values of $\frac{e_1 b}{E_1 b}$ and varying values of $\frac{A}{B}$

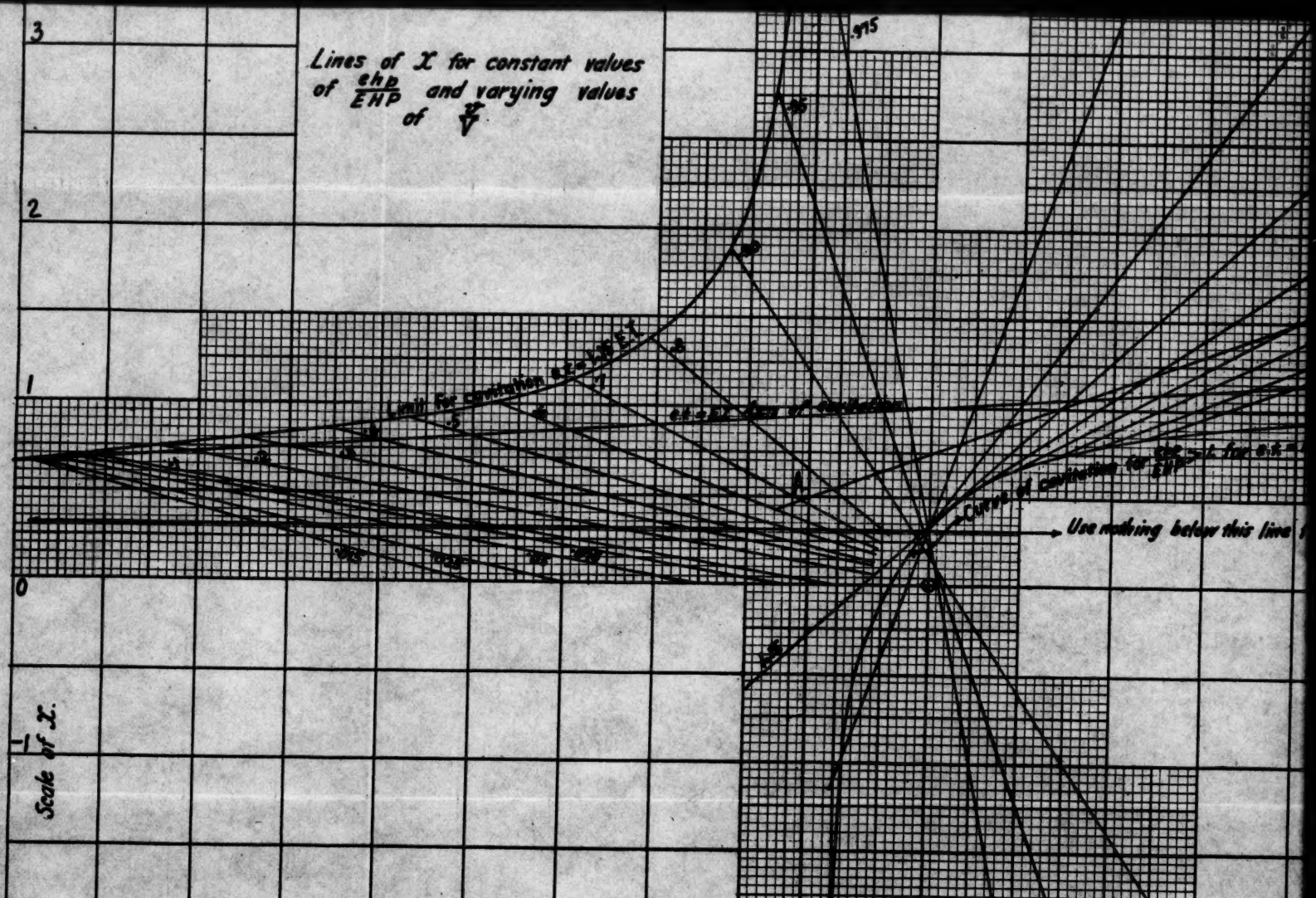

Use nothing below this line for X.


Lines of X for constant values of $\frac{ehp}{EHP}$ and varying values of $\frac{V}{\sqrt{L}}$
B
Use nothing below this line for X.

XU


E.
y.
4
3
2
1
Lines of X for constant values of $\frac{ehp}{EHP}$ and varying values of $\frac{V}{\sqrt{}}$
.915

XU


Lines of X for constant values of $\frac{ehp}{EHP}$ and varying values of $\frac{V}{\sqrt{}}$
3
2
1
0
Scale of X.
.975
Limit for cavitation e.s.=
e.s.=
Use nothing below this line

XU

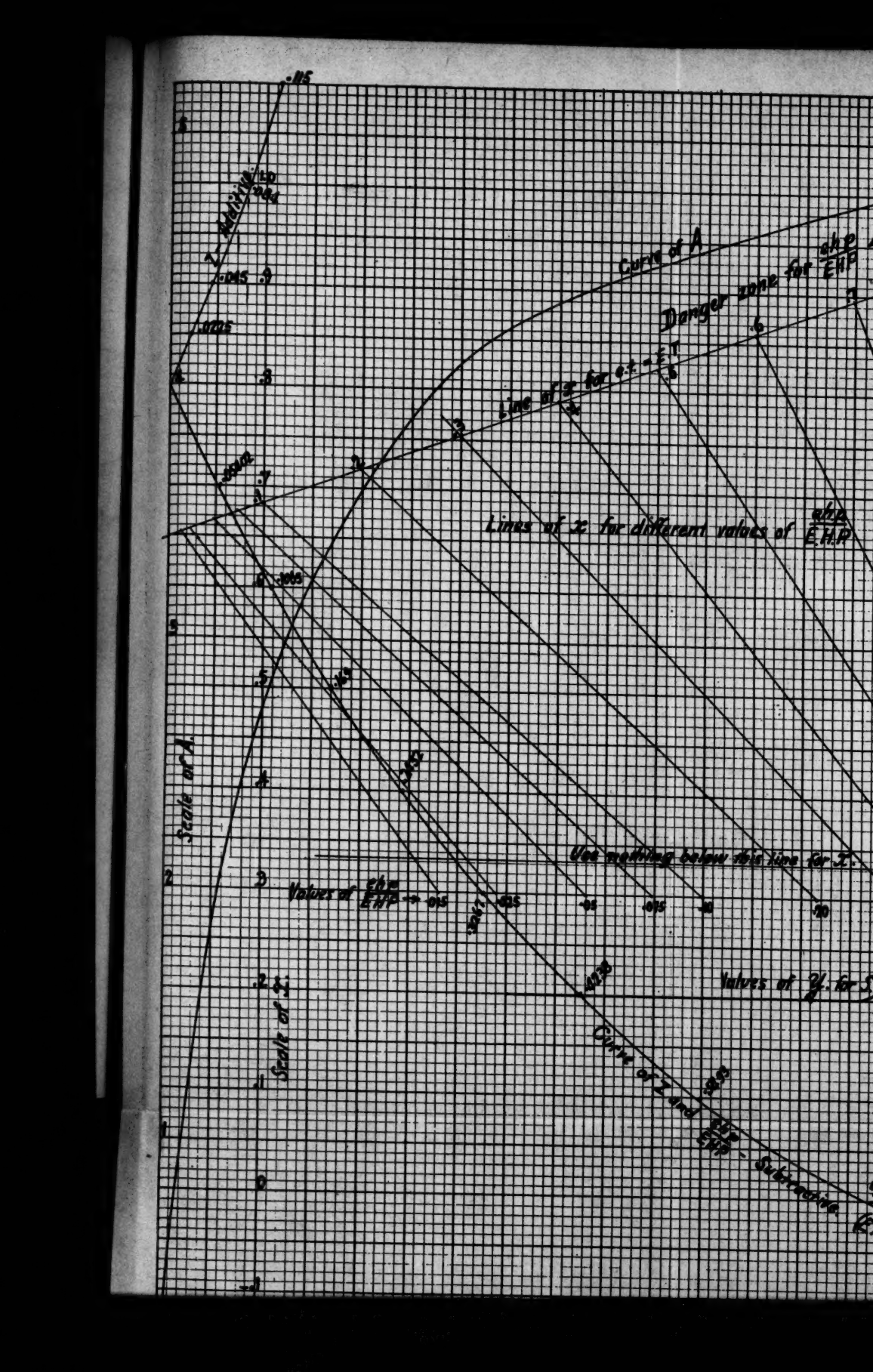
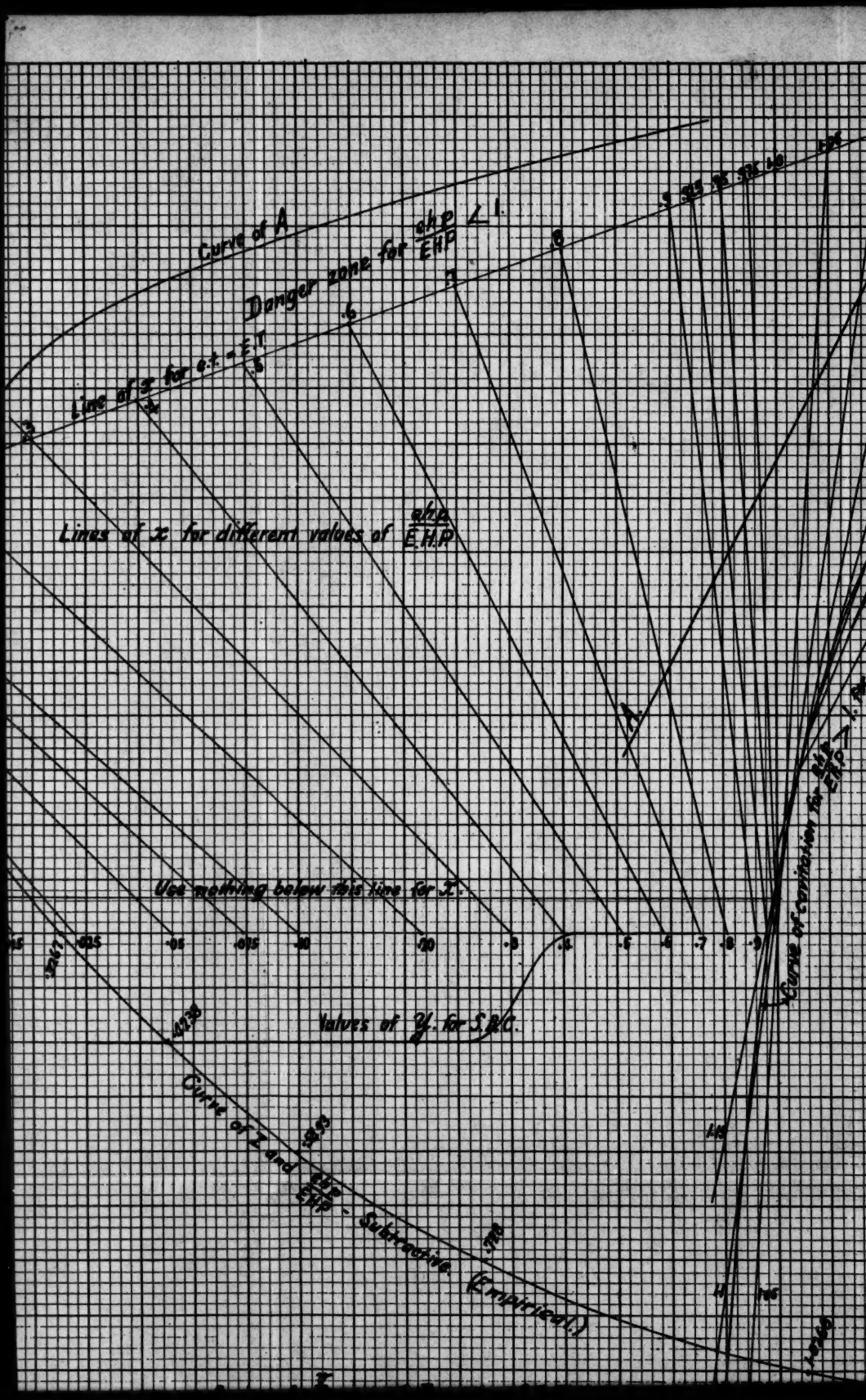

Curve of A
Danger zone for $\frac{ehp}{E.H.P}$
Line of x for 0.2 = $\frac{E.H.P}{ehp}$
Lines of x for different values of $\frac{ehp}{E.H.P}$
Use nothing below this line for x.
Values of $\frac{ehp}{E.H.P}$
Values of $\frac{V}{\sqrt{L}}$ for
Curve of Z and
Subtracting
Scale of A.
Scale of Z.

Chart for
App
① Re
W
② Re
W
Find
Apparent s
③ log Δ
P×
④ Rev
V = Char
v = Desig
S = Char
Δ = Actual
P = Pitch
R = Char
Z = Power c
ehp = Effec
EHP = Char
K = Thrus
A-B = Line
Curve of variation for ehp/EHP = 1 for Δ = 1.15 E.T.
Scale of J
Scale of V
Scale of
(Inverted)


Curve of A
Danger zone for $\frac{shp}{EHP}$ 4.1.
Line of x for e.f. = 4.11
Lines of x for different values of $\frac{shp}{E.H.P}$
Use nothing below this line for X.
Values of $\frac{V_s}{V}$ for S.R.C.
Curve of Z and $\frac{shp}{EHP}$ - Subtractive (Empirical.)
Curve of variation for $\frac{shp}{EHP}$ 4.1
X

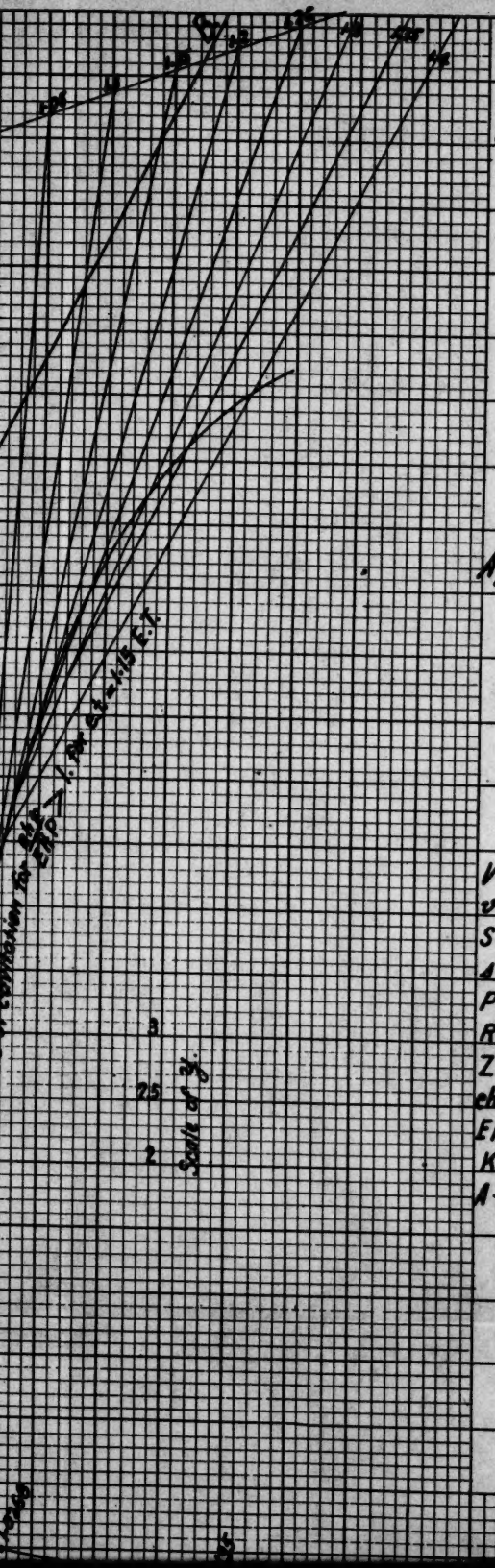


Chart for Estimate of Revolutions.

Approximate Estimates.

① $Revs. = \sqrt[y]{K} \times R \times \left(\frac{ehp}{EHP}\right)^{z}$

Where $\frac{ehp}{EHP} \gtrless 1.$

② $Revs. = \sqrt[y]{K} \times R \times \left(\frac{v}{V}\right)^{x}$

Where $\frac{ehp}{EHP} = 1.$

Final accurate estimate.

Apparent slip $= A = S\frac{K \times V^{x}}{10^{x} \times v^{x}}$ or $S = \frac{K \, IHP_{v} \, V^{x}}{IHP_{V} \times v^{x}}$

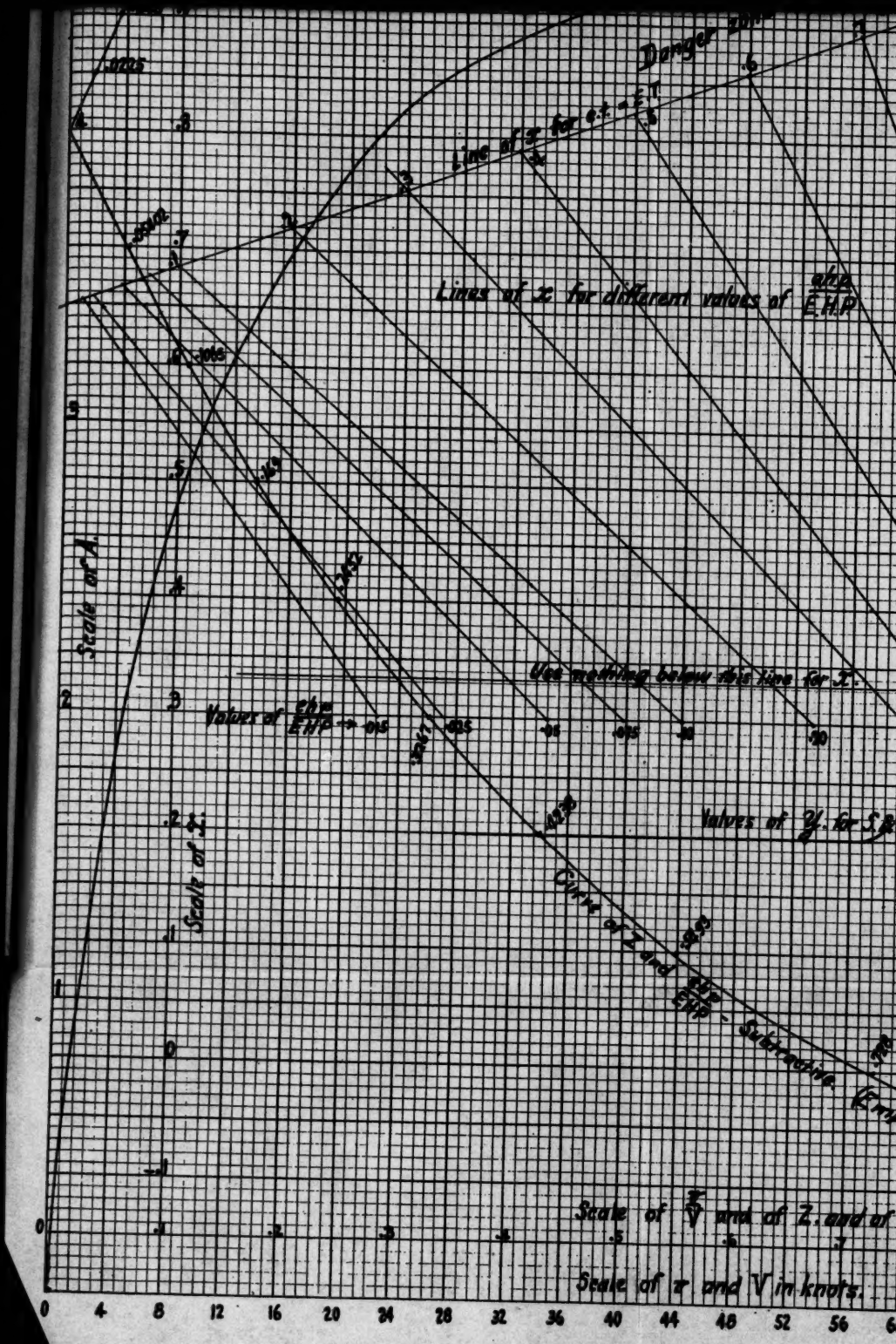
③ $\log A = \log S + \log K + A_{v} - A_{V} - Z$

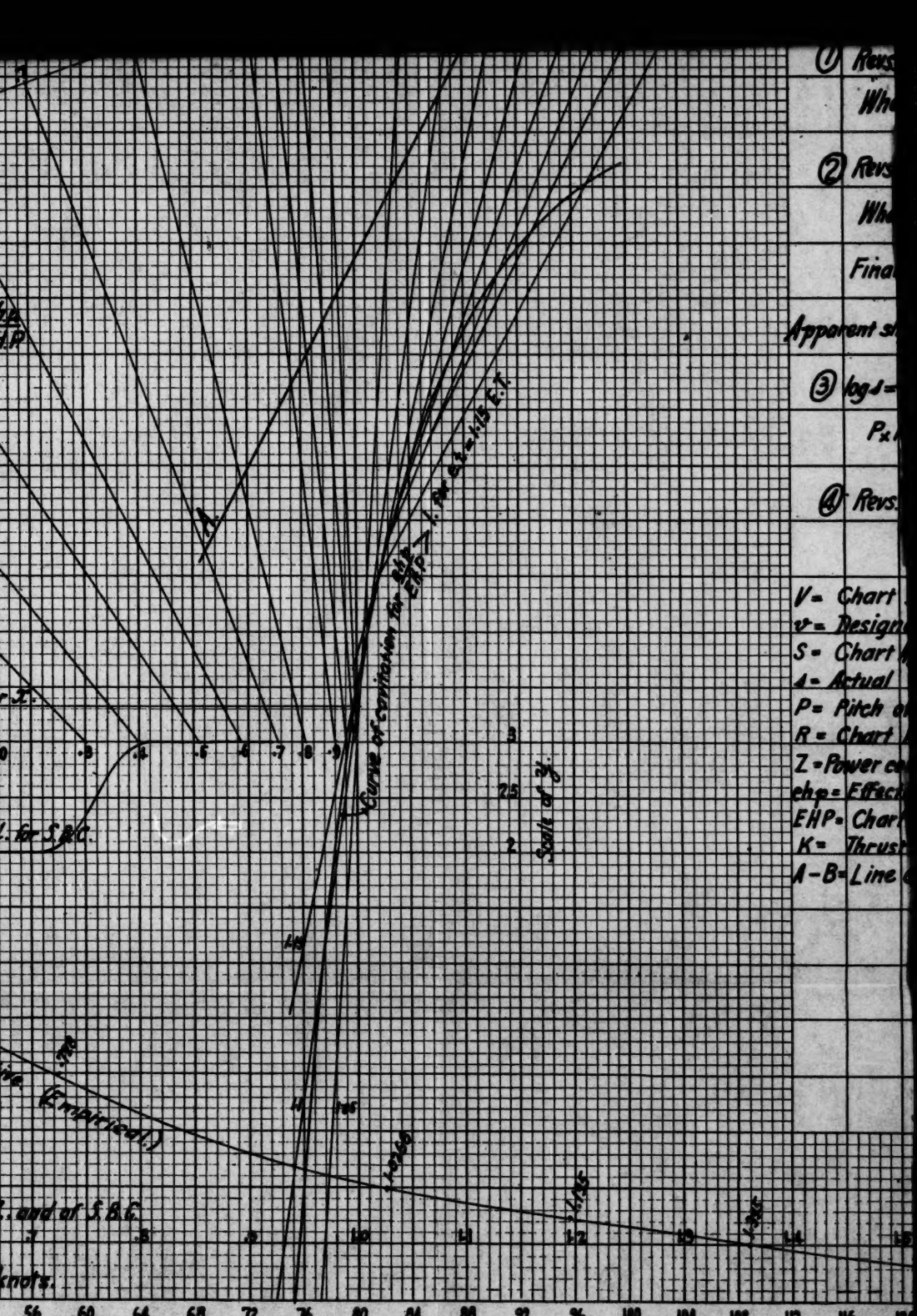
$P \times Revs. = \frac{v \times 101.33}{P \times (1 - A)}$

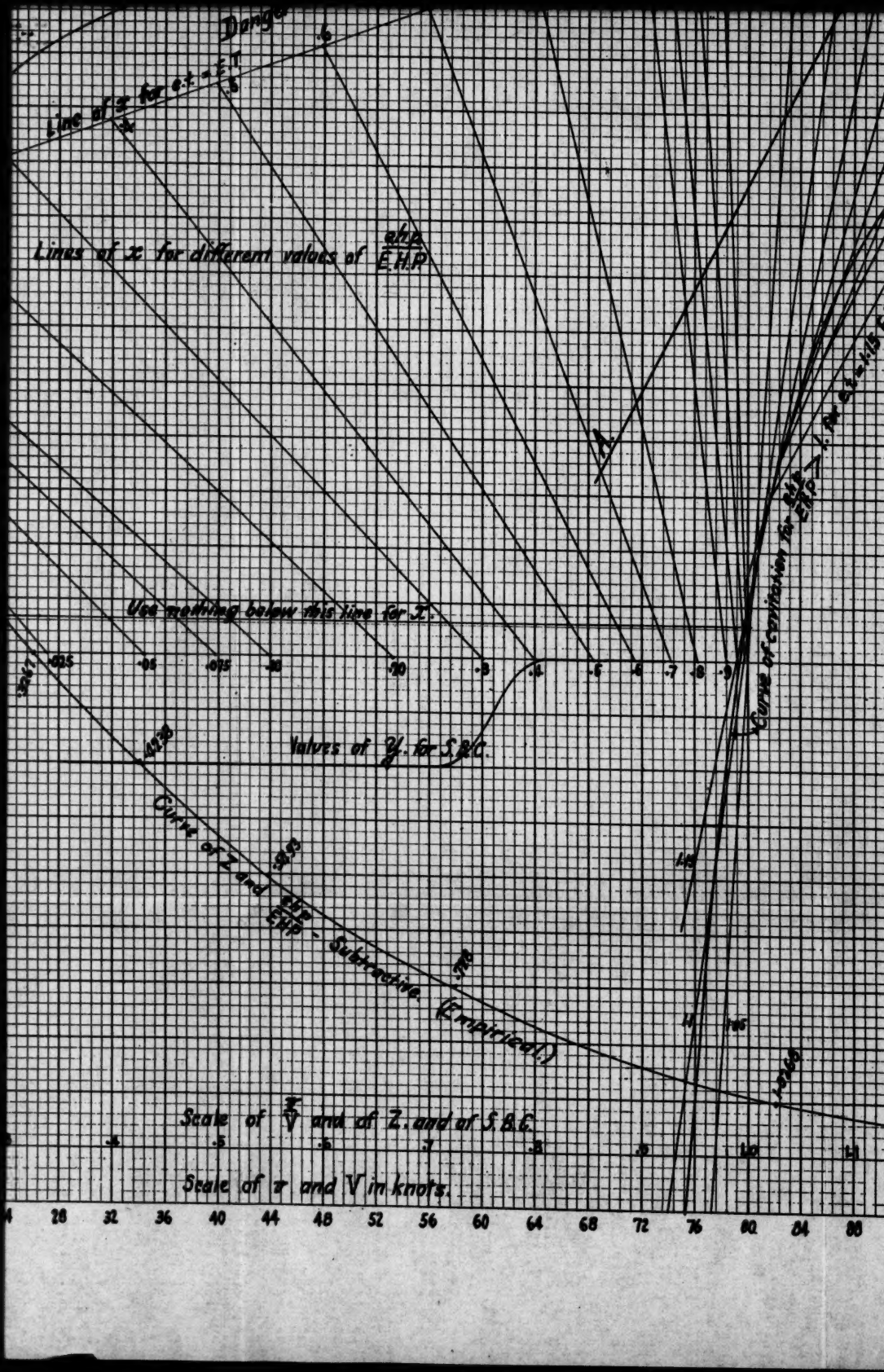
④ $Revs. = \frac{v \times 101.33}{P \times (1 - A)}$

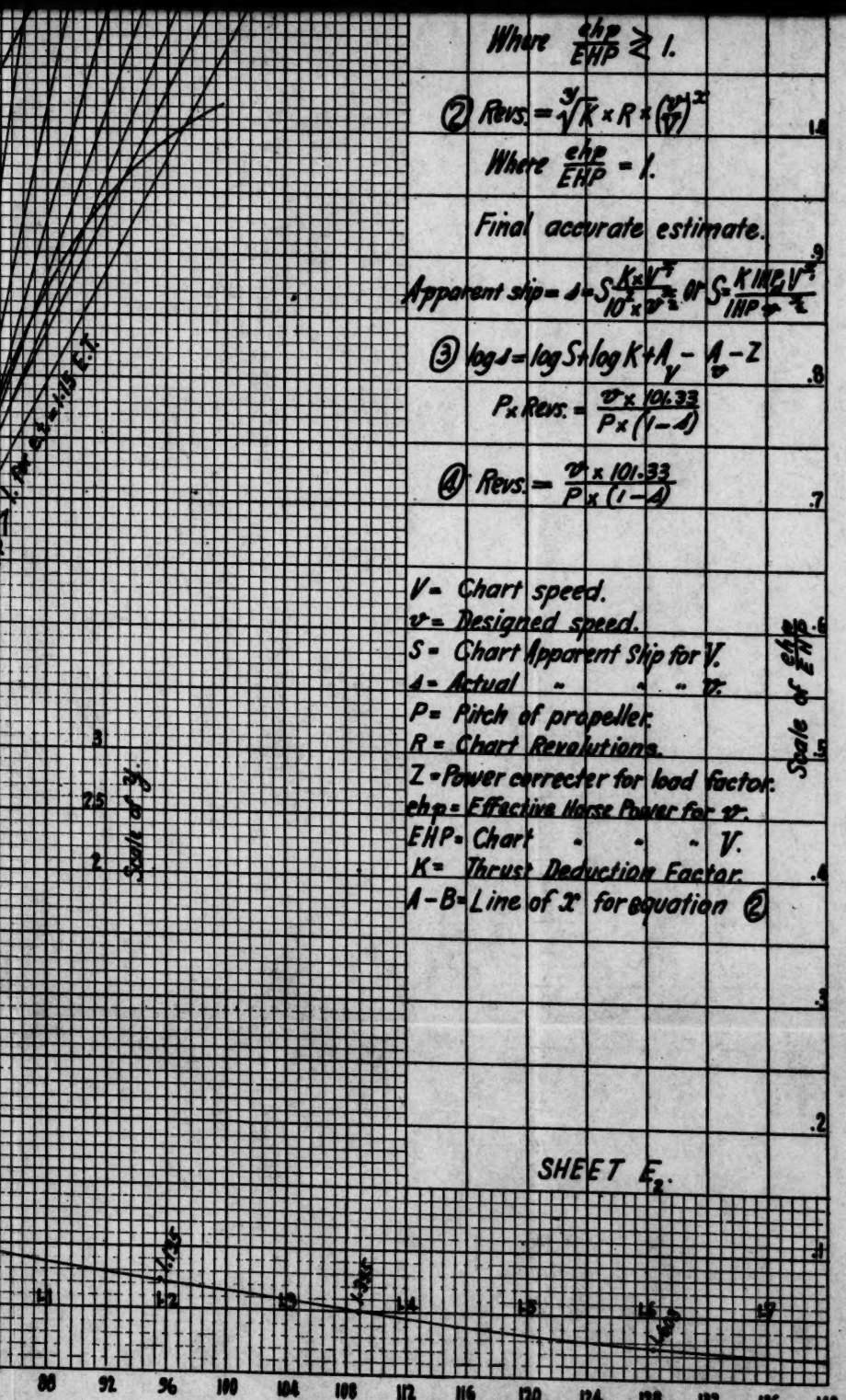
V = Chart speed.
v = Designed speed.
S = Chart Apparent Slip for V.
A = Actual " " " v.
P = Pitch of propeller.
R = Chart Revolutions.
Z = Power correcter for load factor.
ehp = Effective Horse Power for v.
EHP = Chart " " V.
K = Thrust Deduction Factor.
A-B = Line of x for equation ②

SHEET E_2.


Danger zone
Line of x for e.h.p. of T
Lines of x for different values of e.h.p. / E.H.P.
Use reading below this line for T.
Values of e.h.p. / E.H.P.
Values of Y. for S.P.
Curve of Z and e.h.p. - Substracting
Scale of A.
Scale of y.
Scale of Y and of Z. and of
Scale of x and V in knots.
0 4 8 12 16 20 24 28 32 36 40 44 48 52 56


Curve of correction for Δ.H.P. = 1. for 4.5 - kts. E.T.
Scale of Δ.
Apparent s
V = Chart
v = Design
S = Chart
Δ = Actual
P = Pitch o
R = Chart
Z = Power c
ehp = Effect
EHP = Char
K = Thrus
A-B = Line
knots.

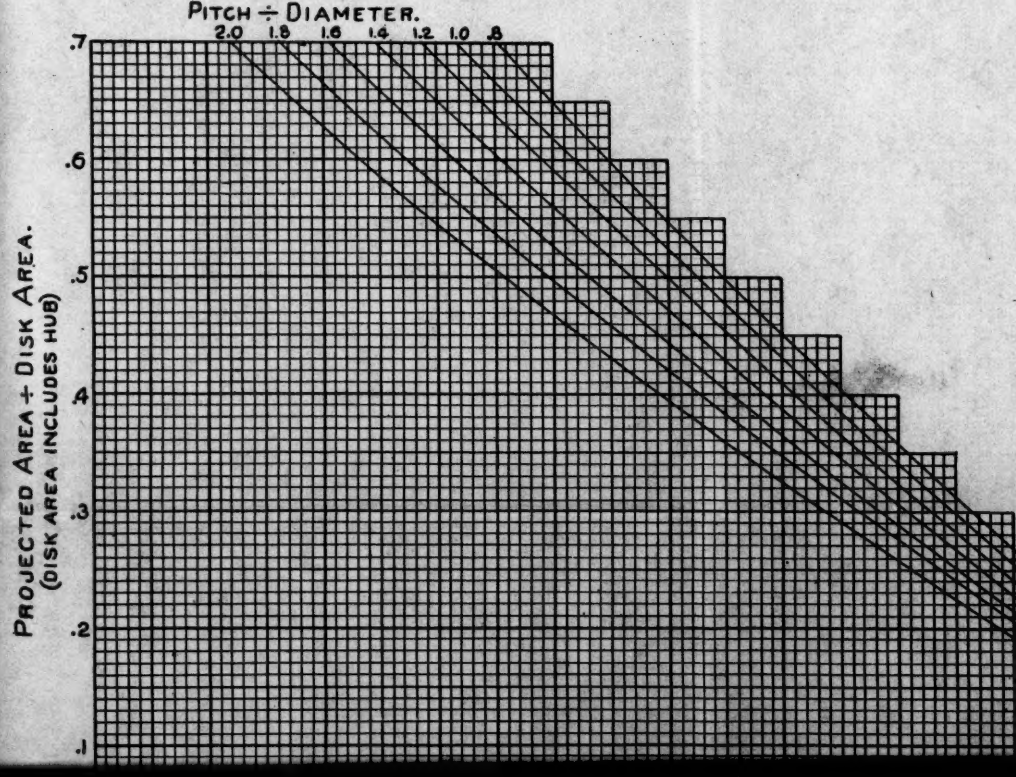

Danger
Line of x for E.H.P.
Lines of x for different values of $\frac{ahp}{E.H.P}$
Use reading below this line for $\frac{V}{\sqrt{L}}$.
Values of $\frac{V}{\sqrt{L}}$ for S.B.C.
Curve of Z and $\frac{ahp}{E.H.P}$ - Subtractive. (Empirical.)
Curve of comparison for $\frac{ahp}{E.H.P}$
Scale of $\frac{V}{\sqrt{L}}$ and of Z. and of S.B.C.
Scale of v and V in knots.


Where $\frac{ehp}{EHP} \geq 1.$
② Revs. $= \sqrt[y]{K} \times R \times \left(\frac{V}{v}\right)^x$
Where $\frac{ehp}{EHP} = 1.$
Final accurate estimate.
Apparent slip $= s = S\frac{K \times V^2}{10 \times v^2}$ or $S = \frac{K\,IHP\,V^2}{IHP_v\,v^2}$
③ $\log s = \log S + \log K + A_V - \frac{A}{v} - Z$
$P \times$ Revs. $= \frac{v \times 101.33}{P \times (1-s)}$
④ Revs. $= \frac{v \times 101.33}{P \times (1-s)}$
V = Chart speed.
v = Designed speed.
S = Chart Apparent Slip for V.
s = Actual " " " v.
P = Pitch of propeller.
R = Chart Revolutions.
Z = Power corrector for load factor.
ehp = Effective Horse Power for v.
EHP = Chart " " V.
K = Thrust Deduction Factor.
A-B = Line of x for equation ②
SHEET E2.
Scale of ehp
Scale of s%
3
2.5
2
1.5
1.4
1.3
1.2
1.1
.9
.8
.7
.6
.5
.4
.3
.2
88
92
96
100
104
108
112
116
120
124
128
132
136
140

DYSON STANDARD PRO
FO
SCREW PROPELLER S
JANUAR
BLADE F

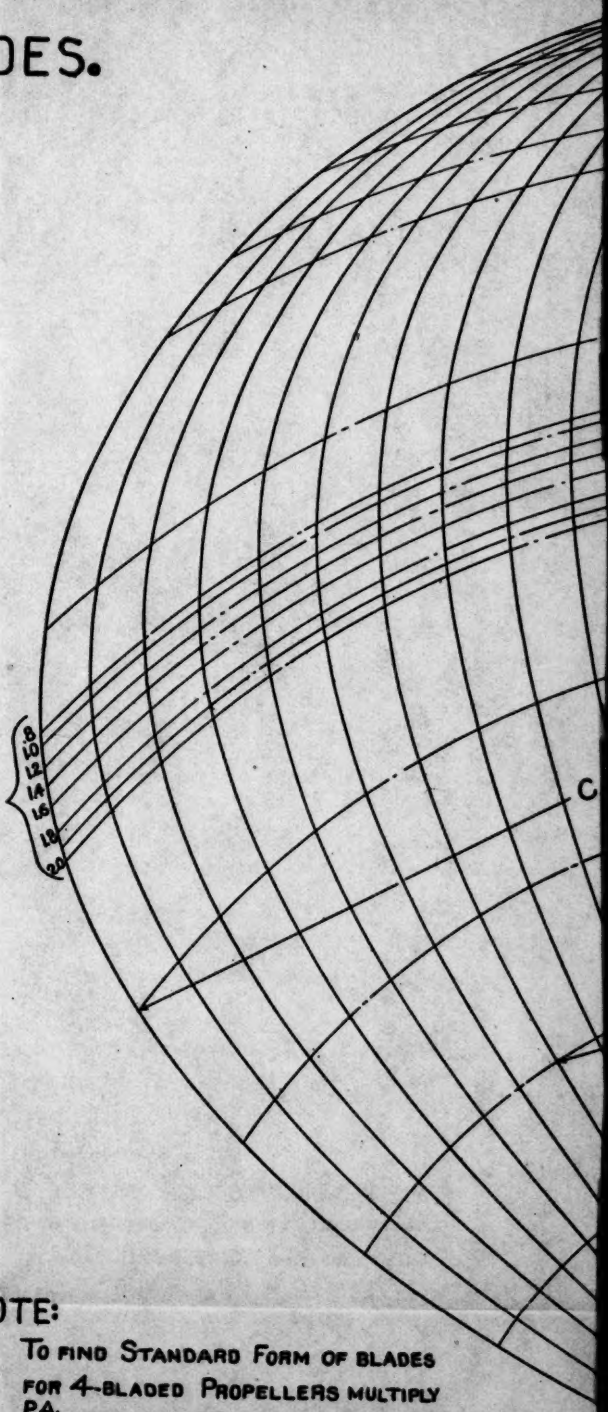
SH

TABLE OF HALF CHORDS, C., RADIUS-UNITY.												
P.A.	DECIMAL PART OF RADIUS WITH HALF CHORDS UNDER.											
D.A.	.2	.3	.4	.5	.6	.7	.8	.9	.925	.95	.975	.9875
.15	.042	.064	.087	.107	.120	.128	.126	.105	.094	.080	.059	.042
.20	.055	.084	.114	.140	.159	.171	.168	.139	.125	.108	.078	.058
.25	.069	.107	.142	.173	.198	.212	.208	.174	.157	.133	.097	.069
.30	.082	.128	.170	.207	.236	.253	.250	.210	.190	.161	.120	.088
.35	.097	.150	.199	.242	.274	.295	.293	.245	.222	.192	.142	.105
.40	.109	.170	.227	.277	.316	.338	.333	.278	.251	.214	.158	.118
.45	.123	.191	.253	.308	.352	.378	.374	.313	.284	.243	.178	.127
.50	.136	.210	.279	.341	.389	.417	.415	.346	.312	.269	.195	.143
.55	.148	.230	.306	.372	.425	.459	.455	.382	.348	.293	.216	.165
.60	.159	.249	.332	.405	.463	.499	.497	.413	.377	.322	.238	.184
.65	.172	.270	.359	.437	.497	.539	.537	.445	.403	.343	.255	.200
.70	.184	.288	.382	.466	.533	.578	.575	.481	.437	.375	.280	.220

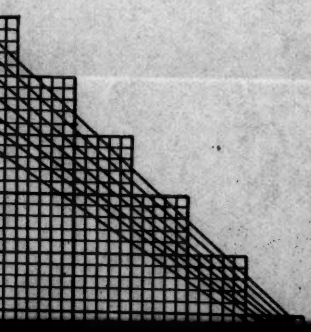


PROJECTED AREA FORMS
FOR
ERS WITH 3-4 AND 2 BLADES.
JANUARY 1913.
DE FORM NO. 1.

Sheet. F_8.



PROJECTIONS OF GREATEST ELLIPTICAL WIDTHS CORRESPONDING TO PITCH RATIOS.



NOTE:

TO FIND STANDARD FORM OF BLADES FOR 4-BLADED PROPELLERS MULTIPLY $\frac{P.A.}{D.A.}$ RATIOS BY .75, AND FOR 2-BLADED PROPELLERS BY 1.5.

THUS:

4-BLADED PROPELLERS WITH $\frac{P.A.}{D.A.}$ = 4

YSON STANDARD PROJECTED AREA FOR

FOR

SCREW PROPELLERS WITH 3-4 AND 2 BLADES.

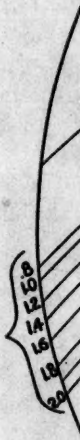
JANUARY 1913.

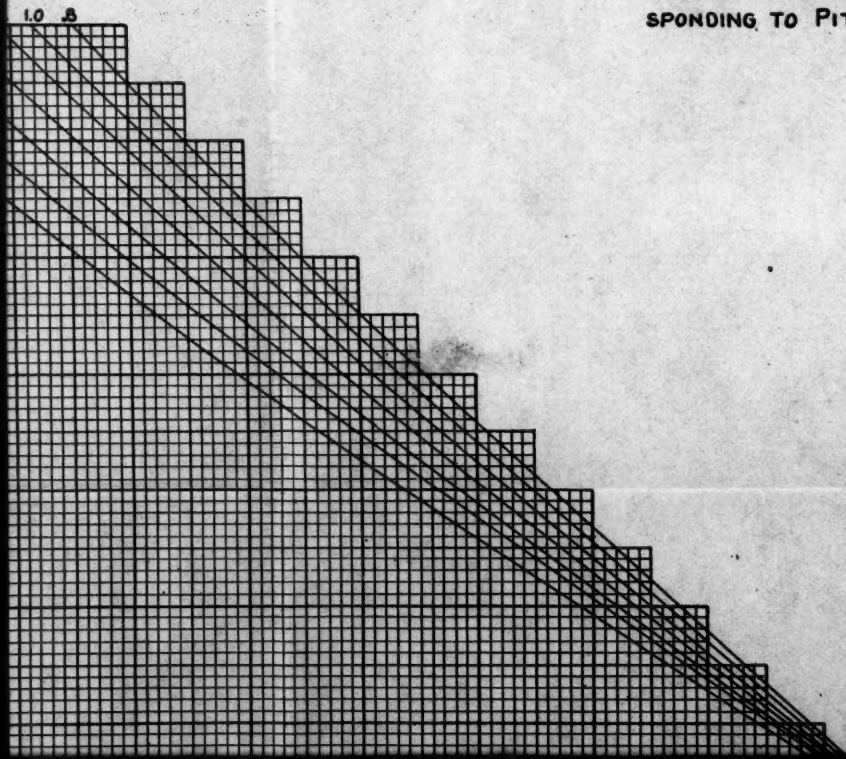
BLADE FORM NO. 1.

C., RADIUS-UNITY.					
TH HALF CHORDS UNDER.					
8	.9	.925	.95	.975	.9875
26	.105	.094	.080	.059	.042
98	.139	.125	.108	.078	.058
08	.174	.157	.133	.097	.069
50	.210	.190	.161	.120	.088
93	.245	.222	.192	.142	.105
33	.278	.251	.214	.158	.118
74	.313	.284	.243	.178	.127
15	.346	.312	.269	.195	.143
55	.382	.348	.293	.216	.165
97	.413	.377	.322	.238	.184
37	.445	.403	.343	.255	.200
75	.481	.437	.375	.280	.220

Sheet. F_8.

PROJECTIONS OF GREATEST ELLIPTICAL WIDTHS CORRESPONDING TO PITCH RATIOS.





NOTE:

To f

FOR

P.A.

D.A.

PRO

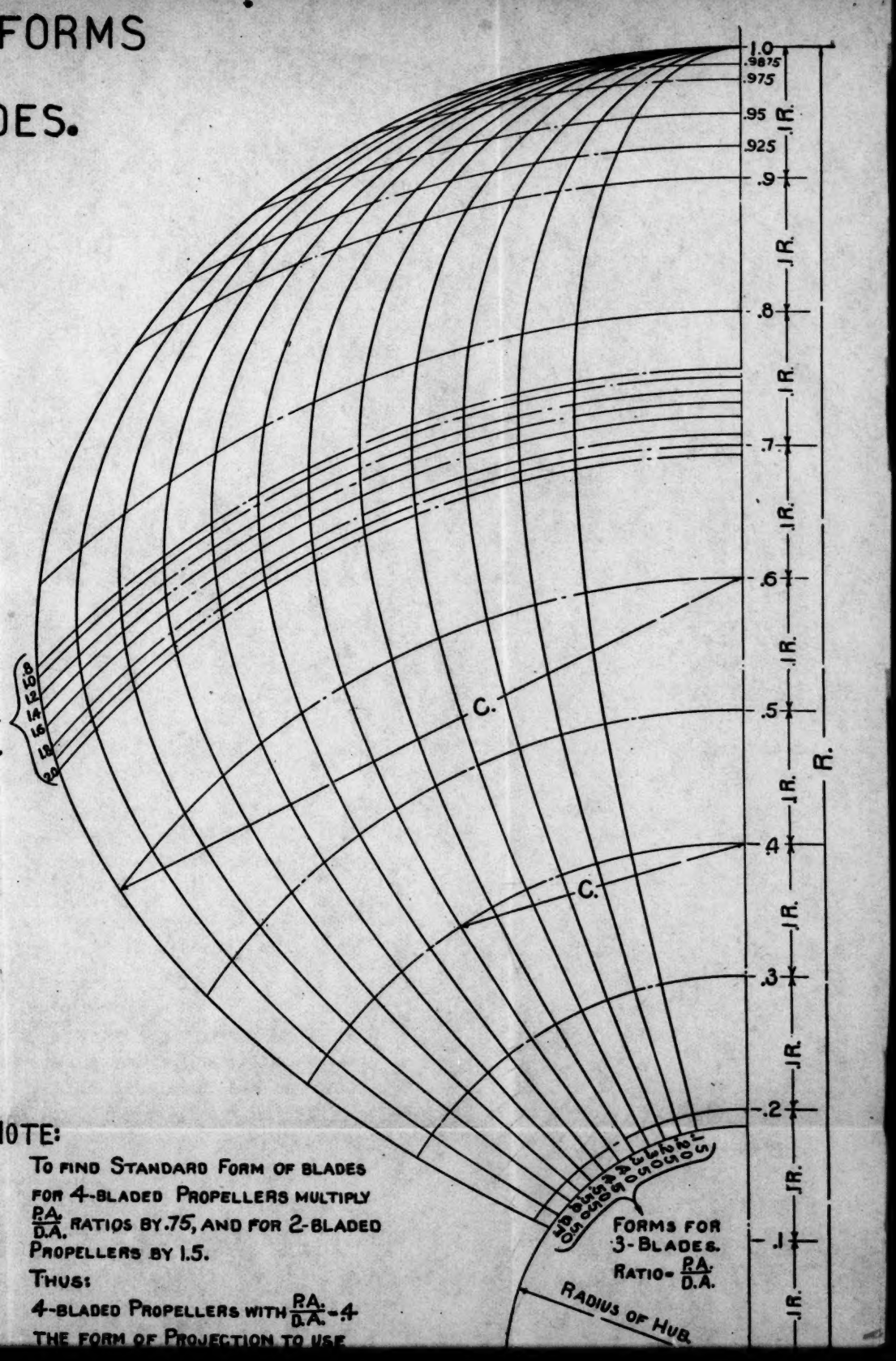
THU

4-B

THE

FORMS

DES.



NOTE:

TO FIND STANDARD FORM OF BLADES FOR 4-BLADED PROPELLERS MULTIPLY $\frac{P.A.}{D.A.}$ RATIOS BY .75, AND FOR 2-BLADED PROPELLERS BY 1.5.

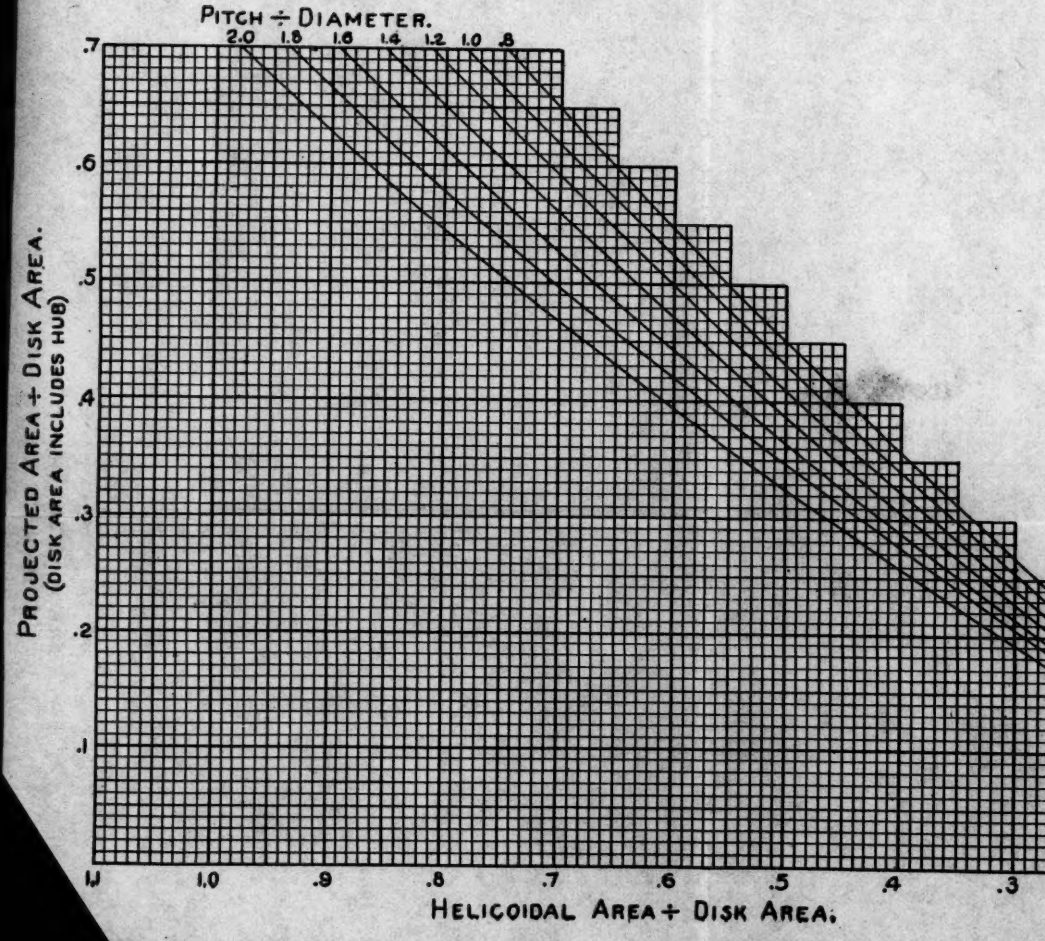
THUS:

4-BLADED PROPELLERS WITH $\frac{P.A.}{D.A.} = .4$

THE FORM OF PROJECTION TO USE

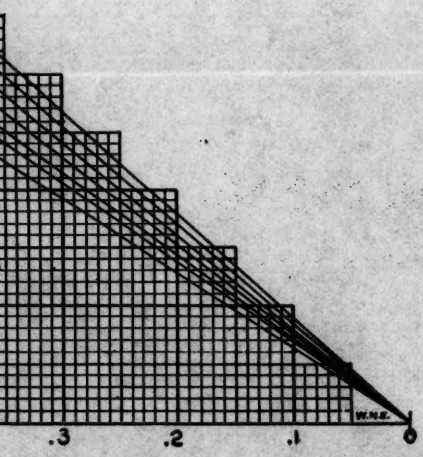
TABLE OF HALF CHORDS, C., RADIUS = UNITY.

P.A.	DECIMAL PART OF RADIUS WITH HALF CHORDS UNDER.											
D.A.	.2	.3	.4	.5	.6	.7	.8	.9	.925	.95	.975	.9875
.15	.042	064	.087	.107	.120	.128	.126	.105	.094	.080	.059	.042
.20	.055	.084	.114	.140	.159	.171	.168	.139	.125	.108	.078	.058
.25	.069	107	.142	.173	.198	.212	.208	.174	.157	.133	.097	.069
.30	.082	.128	.170	.207	.236	.253	.250	.210	.190	.161	.120	.088
.35	.097	.150	.199	.242	.274	.295	.293	.245	.222	.192	.142	.105
.40	.109	.170	227	.277	.316	.338	.333	.278	.251	.214	.158	.118
.45	.123	.191	.253	.308	.352	.378	.374	.313	.284	.243	.178	.127
.50	.136	.210	.279	.341	.389	.417	.415	.346	.312	.269	.195	.143
.55	.148	.230	.306	.372	.425	.459	.455	.382	.348	.293	.216	.165
.60	.159	.249	.332	.405	.463	.499	.497	.413	.377	.322	.238	.184
.65	.172	.270	.359	.437	.497	.539	.537	.445	.403	.343	.255	.200
.70	.184	.288	.382	.466	.533	.578	.575	.481	.437	.375	.280	.220



Sheet. F_8.

PROJECTIONS OF GREATEST ELLIPTICAL WIDTHS CORRESPONDING TO PITCH RATIOS.



NOTE:

TO FIND STANDARD FORM OF BLADES FOR 4-BLADED PROPELLERS MULTIPLY $\frac{P.A.}{D.A.}$ RATIOS BY .75, AND FOR 2-BLADED PROPELLERS BY 1.5.

THUS:

4-BLADED PROPELLERS WITH $\frac{P.A.}{D.A.} = .4$ THE FORM OF PROJECTION TO USE $= .4 \times .75 = .3$

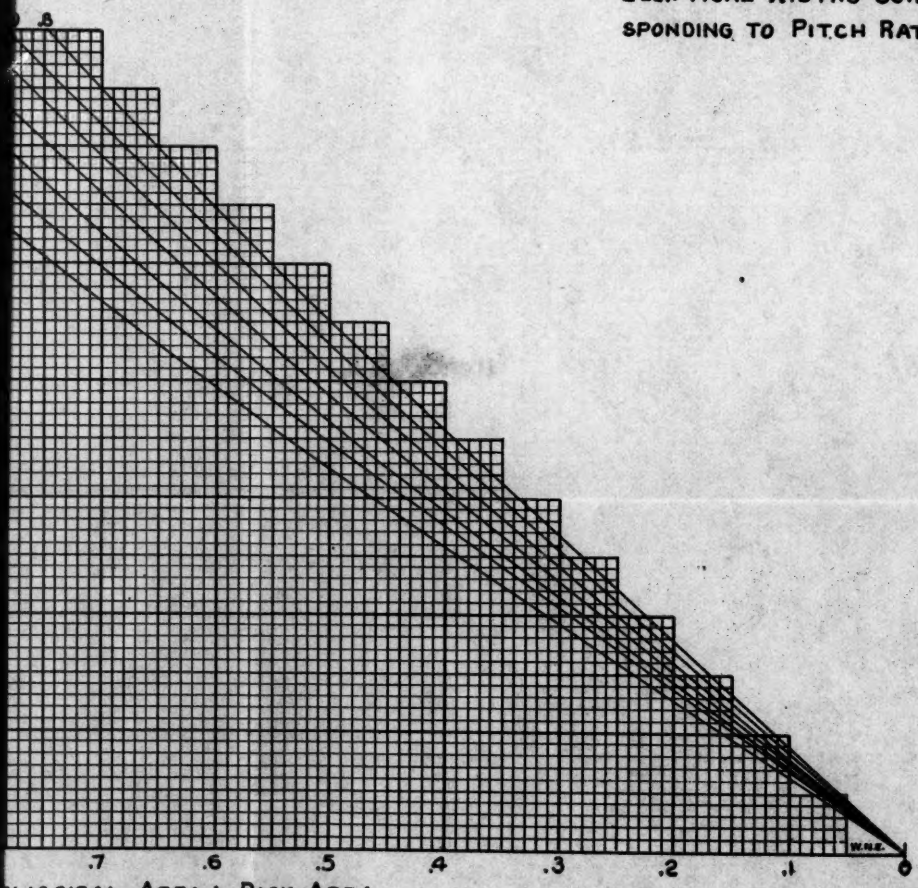
2-BLADED PROPELLERS WITH $\frac{P.A.}{D.A.} = .4$ THE FORM OF PROJECTION TO USE $= .4 \times 1.5 = .6$.

; RADIUS = UNITY.

HALF CHORDS UNDER.				
.9	.925	.95	.975	.9875
105	.094	.080	.059	.042
139	.125	.108	.078	.058
174	.157	.133	.097	.069
210	.190	.161	.120	.088
245	.222	.192	.142	.105
278	.251	.214	.158	.118
313	.284	.243	.178	.127
346	.312	.269	.195	.143
382	.348	.293	.216	.165
413	.377	.322	.238	.184
445	.403	.343	.255	.200
481	.437	.375	.280	.220

Sheet. F_8.

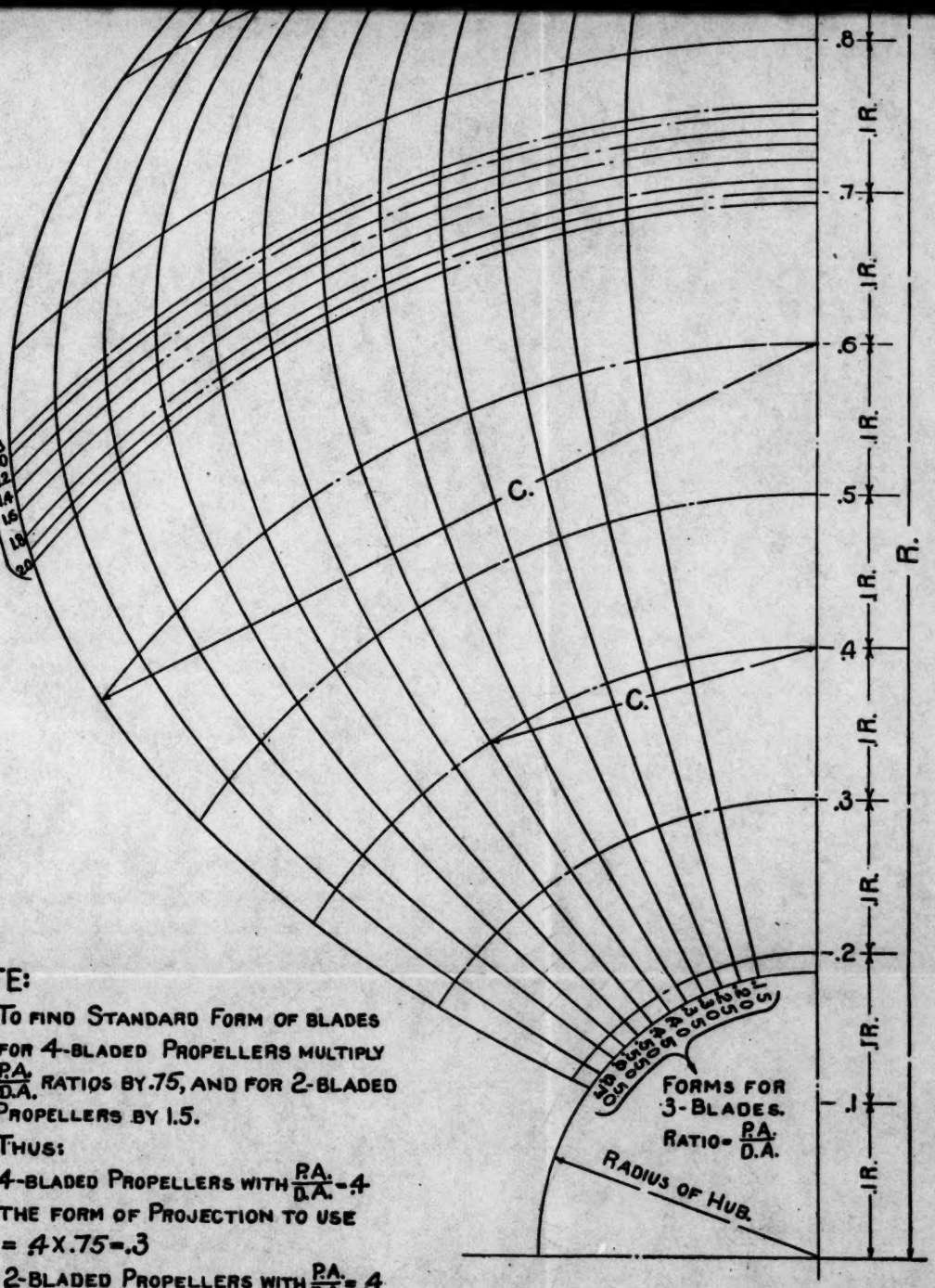
PROJECTIONS OF GREATEST ELLIPTICAL WIDTHS CORRESPONDING TO PITCH RATIOS.



ELICOIDAL AREA ÷ DISK AREA.

NOTE:

TO FIND
FOR 4-B
$\frac{P.A.}{D.A.}$ RAT
PROPELL
THUS:
4-BLADE
THE FO
= 4X.
2-BLAD
THE FO
= 4X



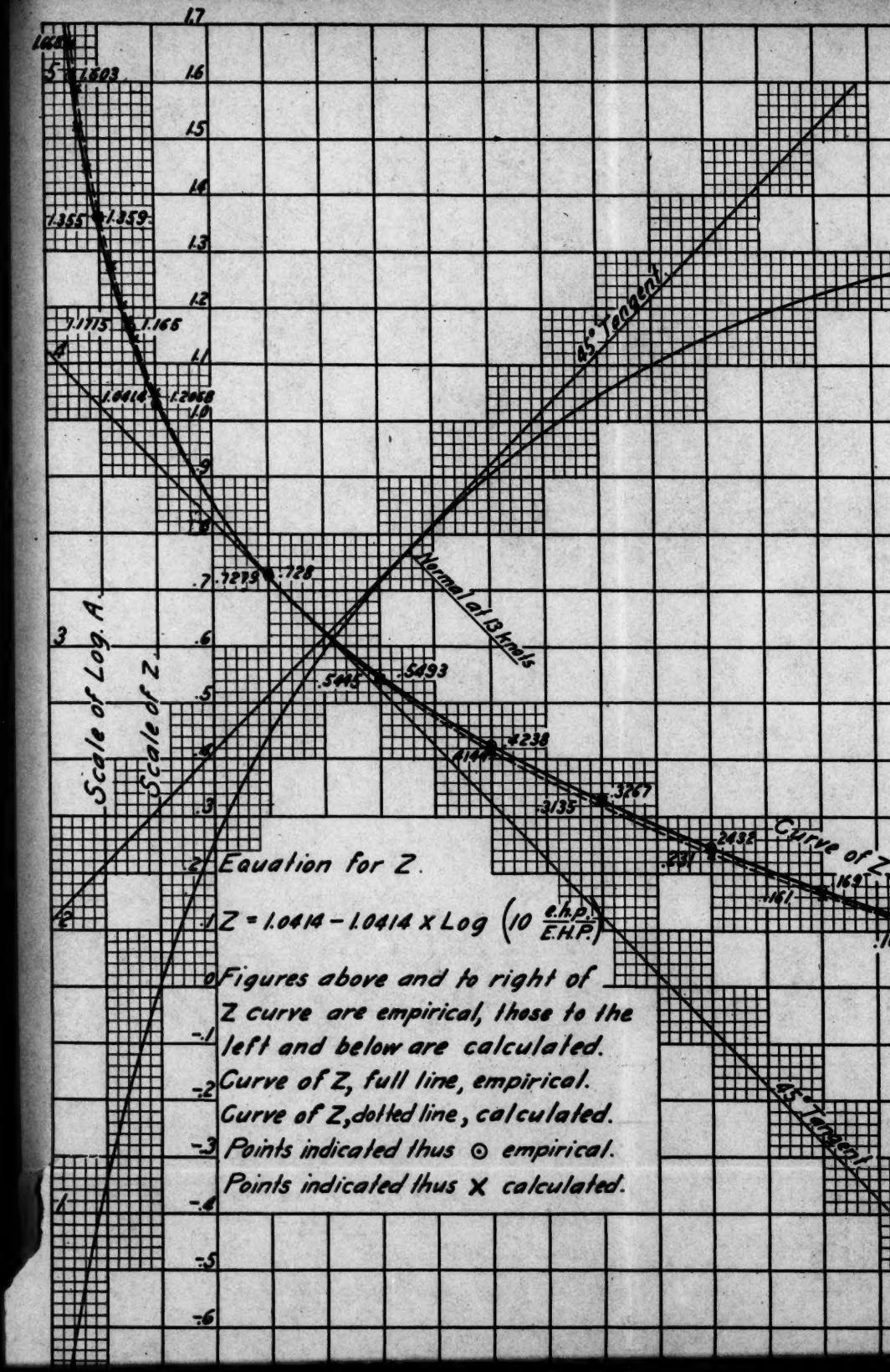
E:

TO FIND STANDARD FORM OF BLADES FOR 4-BLADED PROPELLERS MULTIPLY $\frac{P.A.}{D.A.}$ RATIOS BY .75, AND FOR 2-BLADED PROPELLERS BY 1.5.

THUS:

4-BLADED PROPELLERS WITH $\frac{P.A.}{D.A.}$ = .4
THE FORM OF PROJECTION TO USE
= .4 X .75 = .3

2-BLADED PROPELLERS WITH $\frac{P.A.}{D.A.}$ = .4
THE FORM OF PROJECTION TO USE
= .4 X 1.5 = .6.


1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
-.1
-.2
-.3
-.4
-.5
-.6
1.603
1.355
1.359
1.1715
1.165
1.0414
1.2068
.7279
.728
.5493
.4238
.3767
.3135
.2438
.291
.161
45° Tangent
Normal at 13 knots
Scale of Log. A.
Scale of Z
Curve of Z
45° Tangent
Equation for Z.
$Z = 1.0414 - 1.0414 \times \text{Log}\left(10 \frac{e.h.p.}{E.H.P.}\right)$
Figures above and to right of Z curve are empirical, those to the left and below are calculated.
Curve of Z, full line, empirical.
Curve of Z, dotted line, calculated.
Points indicated thus ⊙ empirical.
Points indicated thus × calculated.

Estimate of Revolutions for Varying Power a

V = Chart Speed.

v = Desired •

I.H.P. or S.H.P. = Chart Indicated or Shaft Horse

i.h.p or s.h.p. = Power of Engine on Propeller Sh

S.H.P. = I.H.P. x .92

s.h.p. = i.h.p. x .92

S = Chart Apparent Slip.

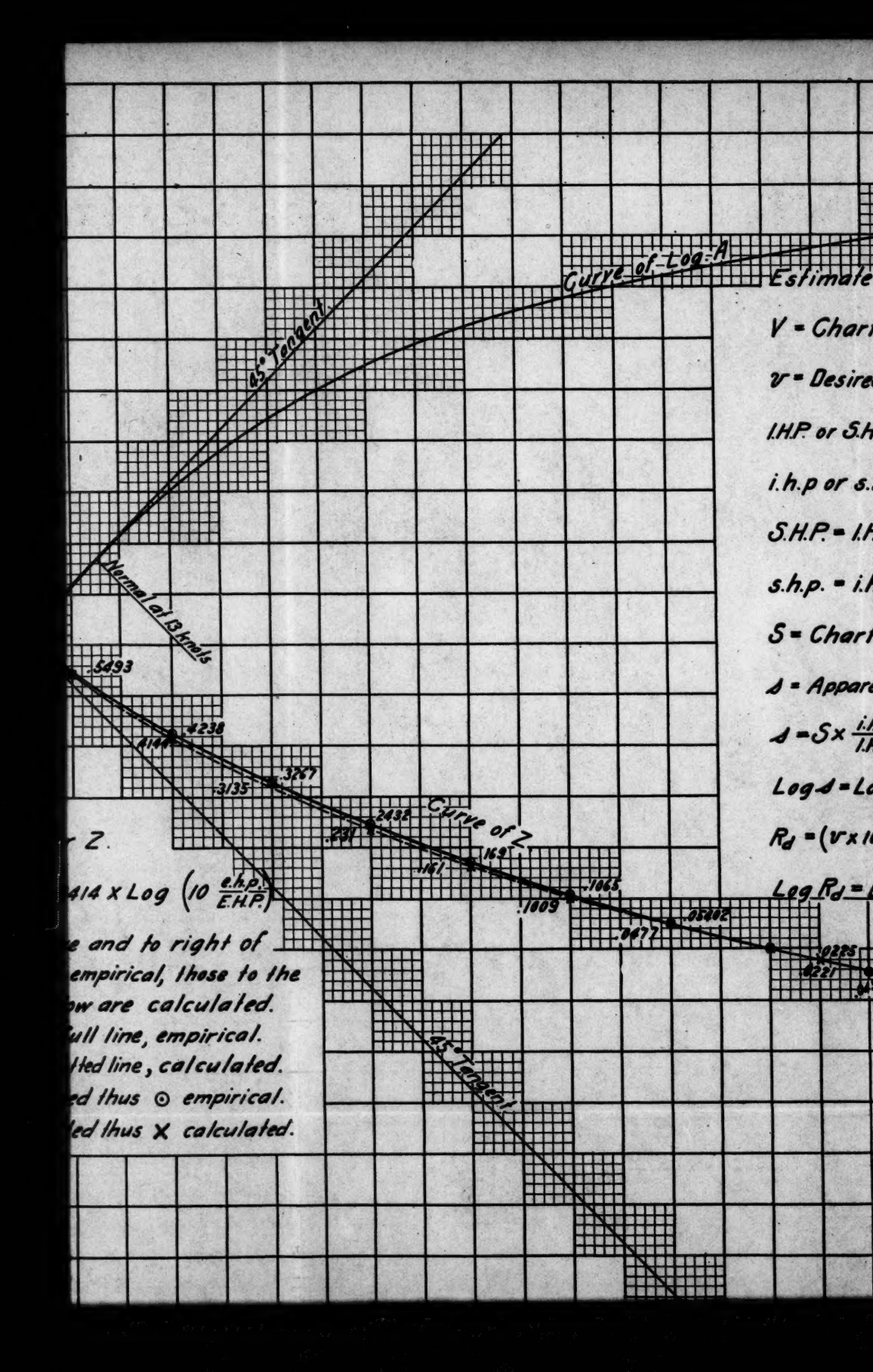
Δ = Apparent Slip at Speed v with Power = i.h.p.o

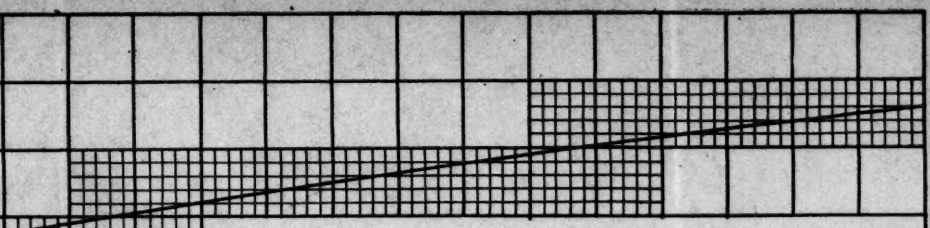
$$\Delta = S \times \frac{i.h.p. \times V^{x_1}}{I.H.P. \times v^{x_2}} = \frac{S \times K \times V^{x_1}}{10^2 \times v^{x_2}}$$

$$\text{Log}\,\Delta = \text{Log}\,S + \text{Log}\ i.h.p + \text{Log}A_V - \text{Log}\,I.H.P. - \text{Log}A_v = \text{Lo}$$

$R_d = (v \times 101.33) \div \{(1-\Delta) \times P\}$ where P = Pitch of Prop

$$\text{Log}\,R_d = \text{Log}\,v + 2.00574 - \text{Log}\,(1-\Delta) - \text{Log}\,P.$$


Curve of Log A
45° Tangent
Normal at 13 knots
.5493
.4238
.3767
.3135
.2432
.231
.161
.1409
.1065
.1009
.0677
.0582
.0225
.0221
Curve of Z
45° Tangent
Z.
414 x Log (10 e.h.p./E.H.P.)
e and to right of
empirical, those to the
ow are calculated.
full line, empirical.
tted line, calculated.
ed thus ⊙ empirical.
led thus X calculated.
Estimate
V = Chart
v = Desire
I.H.P. or S.H
i.h.p or s.
S.H.P. = I.H
s.h.p. = i.h
S = Chart
Δ = Appare
Δ = S x i.h/I.H
Log Δ = Lo
Rd = (v x 1
Log Rd =



imate of Revolutions for Varying Power and Speed.

Chart Speed.

Desired •

P or S.H.P. = Chart Indicated or Shaft Horse Power.

p or s.h.p. = Power of Engine on Propeller Shaft.

.P. = I.H.P. x .92

p. = i.h.p. x .92

Chart Apparent Slip.

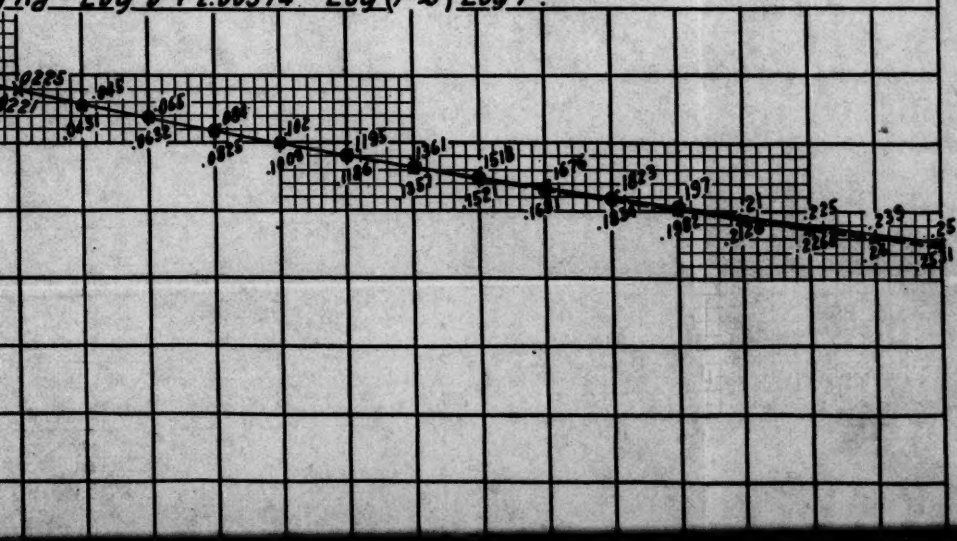
Apparent Slip at Speed v with Power = i.h.p. or s.h.p.

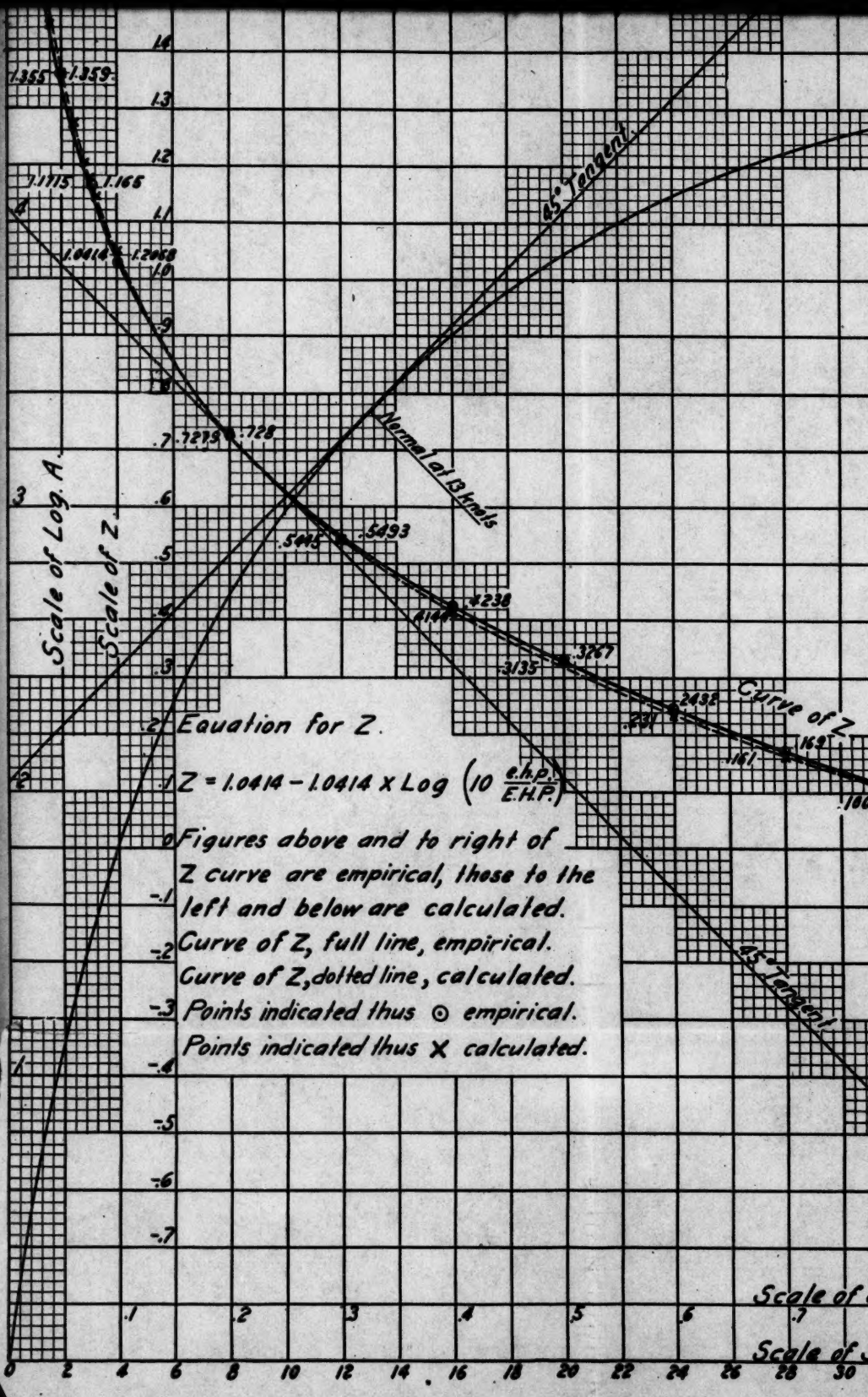
$S \times \frac{i.h.p. \times V^{x_1}}{I.H.P. \times v^{x_2}} = \frac{S \times K \times V^{x_1}}{10^2 \times v^{x_2}}$

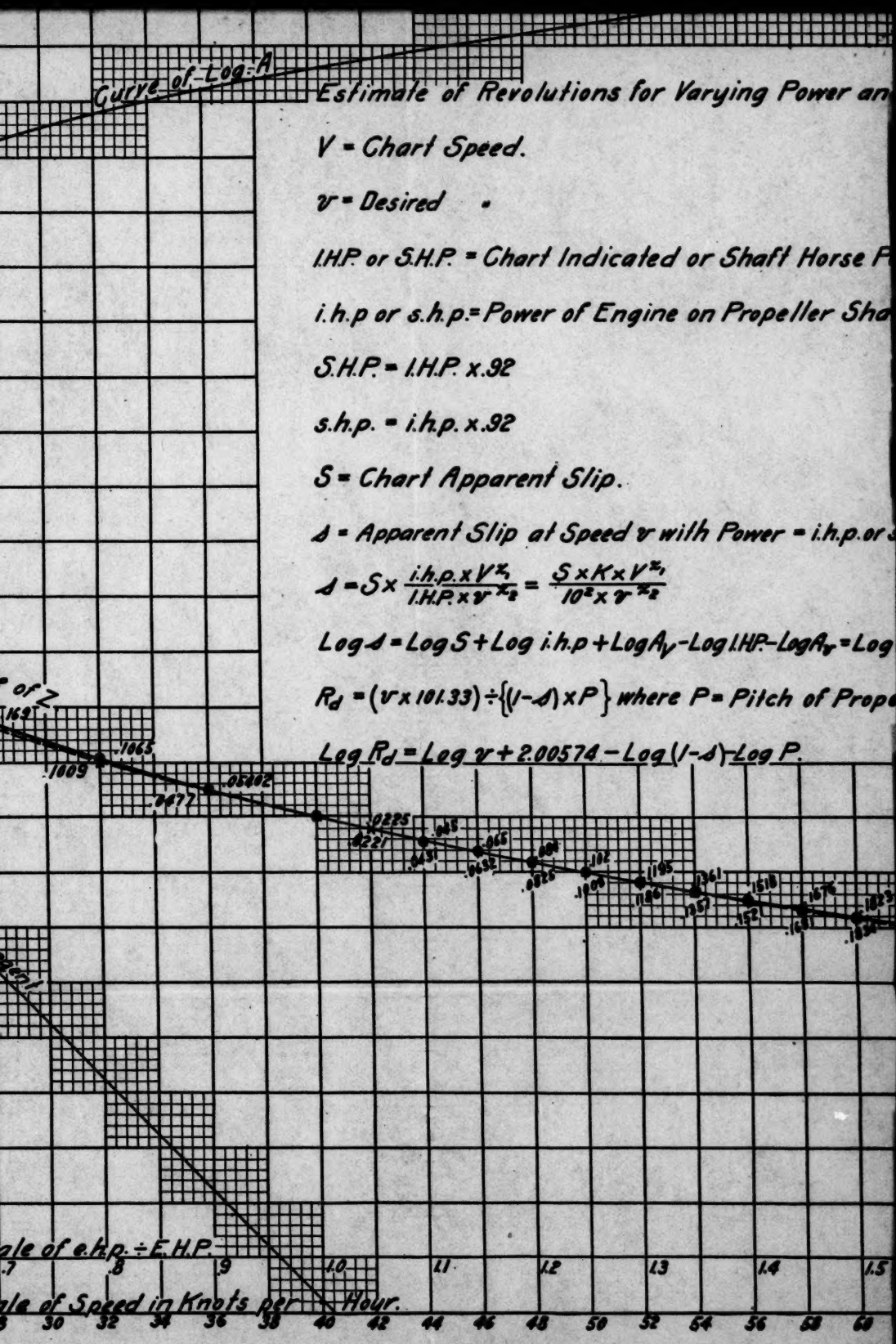
$\log A = \log S + \log i.h.p + \log A_V - \log I.H.P. - \log A_v = \log S + \log K + \log A_V - \log A_v = Z.$

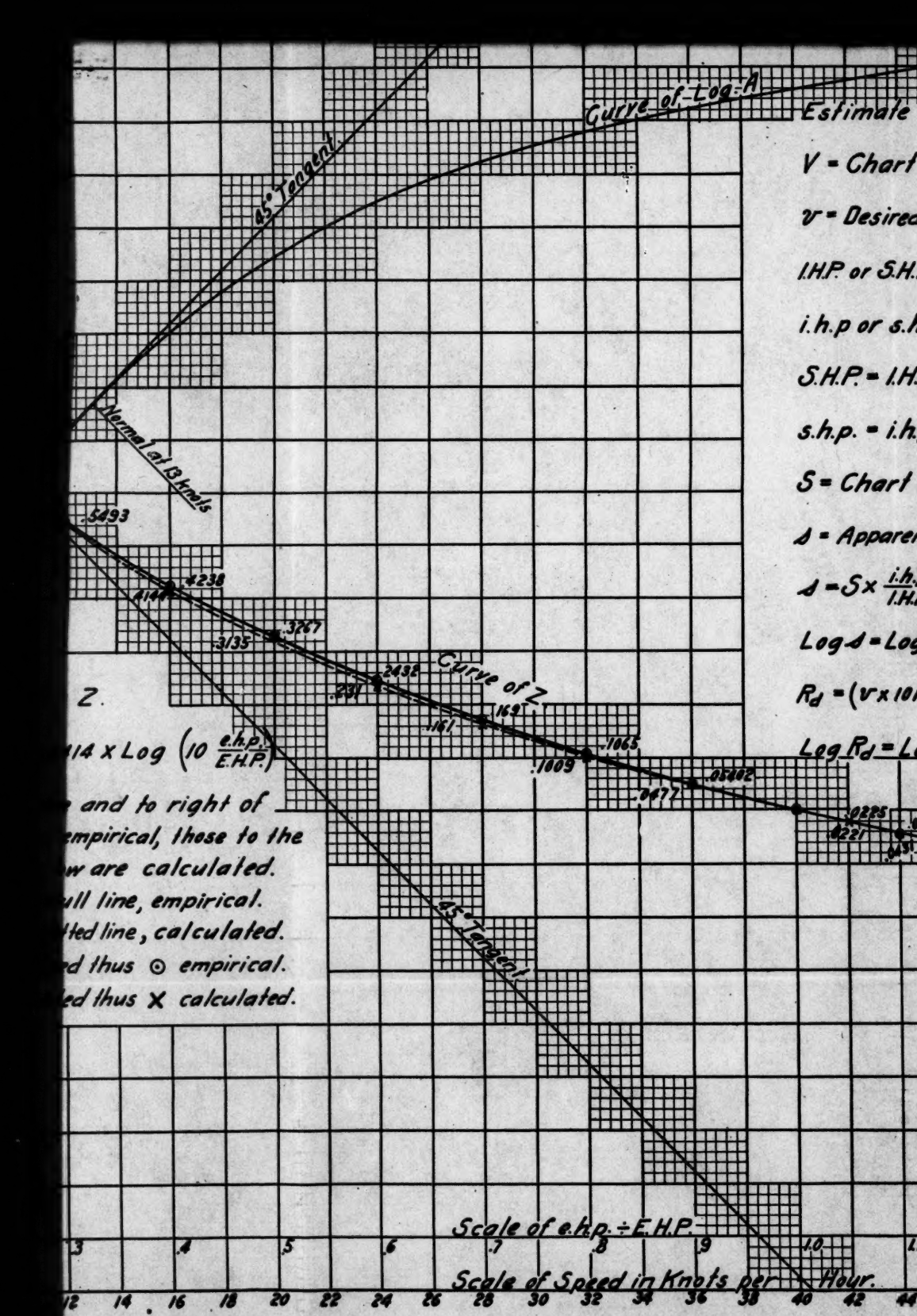
$= (v \times 101.33) \div \{(1-A) \times P\}$ where P = Pitch of Propeller.

$\log R_d = \log v + 2.00574 - \log(1-A) - \log P.$




Scale of Log. A.
Scale of Z.
45° Tangent
Normal at 13 knots
Curve of Z
45° Tangent
1.355
1.359
1.1715
1.165
1.0414
1.2058
.7279
.728
.5495
.5493
.4238
.3767
.3135
.2438
.231
.161
.169
.100
Equation for Z.
$Z = 1.0414 - 1.0414 \times \text{Log}\left(10 \frac{e.h.p.}{E.H.P.}\right)$
Figures above and to right of Z curve are empirical, those to the left and below are calculated.
Curve of Z, full line, empirical.
Curve of Z, dotted line, calculated.
Points indicated thus ⊙ empirical.
Points indicated thus × calculated.
Scale of
Scale of


Curve of Log A
Estimate of Revolutions for Varying Power an
V = Chart Speed.
v = Desired
I.H.P. or S.H.P. = Chart Indicated or Shaft Horse P
i.h.p or s.h.p. = Power of Engine on Propeller Sha
S.H.P. = I.H.P. x .92
s.h.p. = i.h.p. x .92
S = Chart Apparent Slip.
s = Apparent Slip at Speed v with Power = i.h.p. or
$s = S \times \frac{i.h.p. \times V^{x_1}}{I.H.P. \times v^{x_2}} = \frac{S \times K \times V^{x_1}}{10^2 \times v^{x_2}}$
Log s = Log S + Log i.h.p + Log A_V - Log I.H.P. - Log A_v = Log
$R_d = (v \times 101.33) \div \{(1-s) \times P\}$ where P = Pitch of Prop
Log R_d = Log v + 2.00574 - Log (1-s) - Log P.
of Z
.1009
.1065
.0477
.05002
.0221
.0225
.0451
.045
.0432
.066
.0826
.102
.1095
.1180
.1361
.1518
.1676
.1823
.1830
ale of e.h.p. ÷ E.H.P.
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
ale of Speed in Knots per Hour.
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60


Curve of Log A
45° Tangent
Normal at 13 knots
.5493
.4238
.4144
.3767
.3135
.2438
.2317
.1691
.161
.1065
.1009
.0582
.0477
.0225
.0221
Curve of Z
45° Tangent
Scale of e.h.p. ÷ E.H.P.
.3
.4
.5
.6
.7
.8
.9
1.0
Scale of Speed in Knots per Hour.
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
Estimate
V = Chart
v = Desired
I.H.P. or S.H.
i.h.p or s.h
S.H.P. = I.H.
s.h.p. = i.h.
S = Chart
Δ = Apparen
Δ = S x i.h.
I.H.
Log Δ = Log
R_d = (v x 10
Log R_d = L
Z.
14 x Log (10 e.h.p. / E.H.P.)
and to right of
empirical, those to the
w are calculated.
ull line, empirical.
ted line, calculated.
d thus ⊙ empirical.
ed thus × calculated.

imate of Revolutions for Varying Power and Speed.

Chart Speed.

Desired •

or S.H.P. = Chart Indicated or Shaft Horse Power.

or s.h.p. = Power of Engine on Propeller Shaft.

P. = I.H.P. x .92

. = i.h.p. x .92

Chart Apparent Slip.

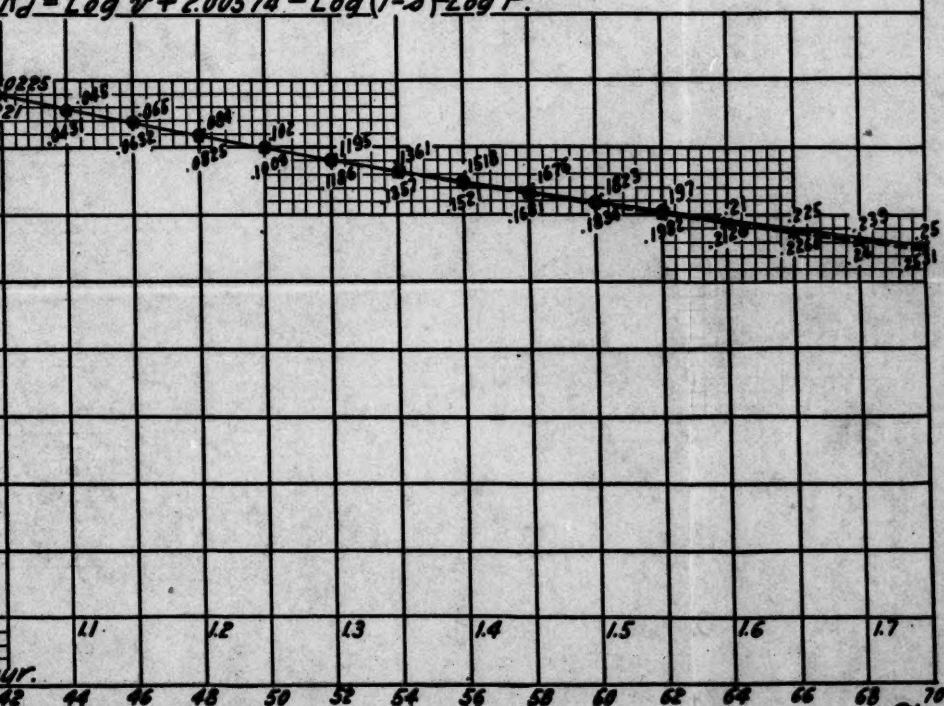
Apparent Slip at Speed v with Power = i.h.p. or s.h.p.

$$S \times \frac{i.h.p. \times V^{x_1}}{I.H.P. \times v^{x_2}} = \frac{S \times K \times V^{x_1}}{10^2 \times v^{x_2}}$$

$$A = \text{Log } S + \text{Log } i.h.p + \text{Log } A_V - \text{Log } I.H.P. - \text{Log } A_v = \text{Log } S + \text{Log } K + \text{Log } A_V - \text{Log } A_v = Z.$$

$$\left\{(V \times 101.33) \div \left\{(1-A) \times P\right\}\right. \text{ where } P = \text{Pitch of Propeller.}$$

$$R_J = \text{Log } v + 2.00574 - \text{Log}(1-A) - \text{Log } P.$$



ur.

Sheet J.

$\frac{P.A.}{D.A.}$ (assumed)	.37	.39	.41
$\frac{e.h.p.}{E.H.P.}$ (assumed)	.8	.8	.8
E.H.P	5,890	5,890	5,890
P × D (Table 2)	199.5	176.9	160.5
D (assumed)	13	13	13
P	15.34	13.62	12.35
$\frac{P}{D}$	1.1815	1.05	.95
S.B.C	.615	.615	.615
V (Table 3)	26.6	24.71	23.23
V^{s-x} (curve 4)	15,689	12,903	11,314
v^{s-x} (curve 4)	8,627	8,627	8,627
10^x	1.2897	1.2897	1.2897
K	1	1	1
S	.106	.109	.111
s	.1495	.1265	.1139
$1 - s$	.8505	.8735	.8861
$R_d = \frac{v \times 101.33}{P(1-S)}$	163.2	179	194.5

Plotting the values of P and R_d we find that P = 14 when R_d = 175. Complete the design as before.

$\frac{P.A.}{D.A.}$	.37	.39	.41
D	13	13	13
R	196.3	205.8	214.4
P	14	14	14
P × D	182	182	182
I.H.P.	8,450	9,660	10,950
E.H.P.	5,370	6,060	6,680
e.h.p.	4,712.5	4,712.5	4,712.5
$\frac{e.h.p.}{E.H.P.}$	.8775	.777	.7055
$\frac{P}{D}$	1.0765	1.0765	1.0765
S.B.C	.615	.615	.615
V	24.3	25.4	26.4
v	21	21	21
$\frac{v}{V}$	.864	.826	.7955
V^{s-x}	12,624	14,322	15,697
v^{s-x}	8,627	8,627	8,627
10^x	1.17	1.325	1.46
K	1	1	1
S	.106	.109	.111
s	.13265	.1365	.1385
$1 - s$	.86735	.8635	.8615
R_d	175.2	176	176.3
S.H.P. (total)	31,100	35,560	40,300
K	1	1	1
$S.H.P._d$	26,570	26,830	27,600

The value of x for $\frac{\text{P.A.}}{\text{D.A.}} = .39$ on sheet E_2 shows that this screw is safe against cavitation, so this screw would be chosen; the full data for the screw would be:

$\frac{\text{P.A.}}{\text{D.A.}} = .39$	$\frac{e.h.p.}{\text{E.H.P.}} = .777$
D = 13 feet	R = 205.8
P = 14 feet	R_d = 176
S.H.P. = 35,560	K = 1
S.H.P._d = 26,830	$s = .1365$
V = 25.4	$1 - s = .8635$
$\frac{v}{V} = .826$	

It will be found that the two methods of estimating revolutions will usually differ very little, and the screws obtained by the two methods of design will be practically the same; in the case of full-bodied ships, however, there will be considerable difference between the two methods, and it will be found that the "slip" method will give the more accurate results.

There are included in this article a full set of Dyson's charts. Most of these charts appeared in the "Mystery of the Screw Propeller," but they are reproduced here as some slight modifications have been made and additional data included. Sheet A has not been changed. Sheet B is new and shows the effect of the appendages for all values of $v \div \sqrt{\text{L.W.L.}}$ Sheet C has been changed slightly, but its application is the same as before. Sheet D gives curves of $(1 - s)$ instead of curves of P.T._p and E.T._p. Sheet E is practically unchanged and sheet E_2 is merely a large scale reproduction of a part of sheet E and also includes some additional data.

I have read the foregoing article with a great amount of interest and consider the work done by Lieutenant Robinson of marked value in the solution of propeller problems. The

curve deduced by him for the estimate of revolutions for varying values of power and of speed of ship is of especial value and supplies fully the one important missing factor in my own work. Mr. Robinson is to be congratulated on the value of the work which he has here submitted after a vast amount of labor which can only be appreciated by one who has gone deeply into the propeller problem.

C. W. DYSON.

SPARK PLUGS.

By LIEUTENANT COMMANDER J. O. FISHER, U. S. N., MEMBER.

In operation in service spark plugs are apparently of variable quality. Similar brands installed in different engines of the same type are at different times and on different ships reported as being both satisfactory and unsatisfactory, reliable and unreliable, durable and ephemeral, in operation. On numerous requisitions it has been certified that a particular brand of spark plug and no other will perform the service required.

These reports of operation in service and statements on requisitions are paradoxes, the underlying truth of which leads only to confusion in attaining the desired result—a supply of spark plugs, on annual contract, which are durable, reliable and satisfactory in use on all types of gasoline engines in power boats in the naval service.

The simplest conception of a spark plug is that of an electrical conductor, connected at one end to a source of electricity and separated from a ground at the other end by a spark gap.

In a gasoline engine the electric current must be carried through the cylinder wall by a conductor to the spark gap located in the combustion chamber under conditions as follows:

(*a*) The electrical conductor must be insulated electrically from the cylinder wall.

(*b*) The insulation must stand the high heat of the combustion space at one end while exposed to the atmosphere and spray at the other.

(*c*) The joint between the insulator and the conductor and

between the insulator and the cylinder wall must be gastight when exposed to heat and pressure of combustion.

(*d*) There must be good heat conduction between the spark-gap terminal and the cylinder wall, or overheating of spark gap with consequent pre-ignition and rapid wear at spark-gap terminals will result. Therefore the insulation must be a conductor of heat.

(*e*) The insulation must withstand the action of oil.

(*f*) The cylinder wall in vicinity of spark-gap terminals must be adequately cooled.

(*g*) The electrical resistance across spark gap at time of ignition must be less than that between any other part of electrical conductor and cylinder. This is effected by the compression used in the engine cylinder. The higher the compression the greater the electrical resistance across spark gap, and consequently the better the insulation required.

(*h*) High compression also increases the temperature and pressure of combustion, and therefore not only requires better electrical insulation but also better heat conduction from spark-gap terminals to cylinder cooling water.

To summarize:

(*a*) There must be good heat conduction between sparking points and the cylinder cooling water.

(*b*) There must be electrical resistance between the conductor carrying the current to the spark gap and the cylinder wall; and the insulation used must (1) have heat conductivity; (2) have sufficient mechanical strength to make a gastight joint with the electrical conductor and with the cylinder wall, and (3) withstand action of oil and spray.

The commercial insulating materials used by various manufacturers, with their characteristics, are as follows:

Kaolin.—A white china clay, chief ingredient in the mineral kaolinite, hydrous silicate of aluminum. It is highly refractory. One of principal materials employed in manufacture of porcelain.

Lava.—A mineral talc, hydrated magnesium silicate similar to soapstone, pumice or talc. Slightly soluble in hydrochloric

acid but is not attacked by other acids or alkalies. In natural state can be machined with same facility as brass. No volume change under influence of moisture. Very low coefficient of expansion. After machining is baked to 1,100 degrees C. and becomes very hard. Insulating resistance is high.

Lavite.—Patented material, light buff or cream colored; compressive strength 20,000 to 30,000 pounds per square inch. Compares with glass in hardness; not affected by temperatures up to 1,000 degrees C.; unaffected by acids except aqua regia.

Mica.—Is a refractory material constituted of the double silicate of alumina or magnesia, and potash or soda, combined with varying proportions of potash, soda and other impurities. Iron in excess colors it gray or black; magnesia tends to darken the color; aluminum and potassium silicate tend to make the mica transparent. Mica crystallizes in laminated form and may be split along its axis to sheets as thin as .006 m.m. It has a high dielectric strength and is suitable to withstand high temperatures. However, in its natural state it is not flexible nor uniform, and permits large surface leakage, so that most mica is reconstructed and put on the market in the form of micanite, megomit, megotalc, etc. It is not affected by heat until a temperature of several hundred degrees centigrade is reached, when the laminae separate in the harder varieties and tend to disintegrate into small scales or plates. It can withstand great mechanical pressure perpendicular to the plane of cleavage.

Mica Products.—Many products are manufactured from mica, including paper, cloth, plate and molded insulation. In some cases the strips of mica are mounted on paper or cloth, in alternate layers, using an insulating binder such as shellac. Molded products are usually made from ground mica mixed with a binder, and sometimes mixed with other insulating materials such as asbestos, or a gum or compound.

Soapstone.—Is a kind of soft stone, which is soapy or slightly oily to the touch. It is also known as *Steatite* or massive variety of talc or grayish-green or brown color. It will withstand very high temperatures; it is soft, not very strong, not affected

by acids, oils or alkalies; can be machined, drilled and sawed, and absorbs moisture.

In the opinion of certain manufacturers the best grade of steatite for spark-plug insulation comes from Germany.

Porcelain.—The three principal constituents of electrical porcelain are feldspar, clay and silica. There are three feldspars, the most important or potash feldspar, soda feldspar, and lime feldspar. The two clays used are ball clay and china clay or kaolin. Standard mixture is 20 parts feldspar, 50 parts kaolin, and 30 parts quartz. The feldspar acts as a flux to unite the other constituents when fired. There are two processes of manufacture, the dry and the wet process.

Dry-Process Porcelain.—The moist, raw mixture is molded under high pressure and vitrified by usual firing process. This material is very porous.

Wet-Process Porcelain.—The raw ingredients are mixed with water, placed in a filter press and surplus water extracted, leaving a wet plastic mass. This mass is remixed to make it more homogenous, molded to approximate final shape and dried. When fairly dry it is machined to final shape, dipped in glazing bath and fired. The finished glaze is virtually a species of glass.

A consideration of the various insulating materials listed will demonstrate that they are all classed as heat-resisting insulation.

Electrical insulation resistance is separable into two components, volume resistivity and surface resistivity. The leakage path through the substance or interior of the dielectric is electrically in parallel with the surface leakage path composed of a film of moisture or oil (with the frequent addition of dust or foreign matter) on the surface of the dielectric.

Surface resistivity is undoubtedly more important than volume resistivity in a spark plug, and to obtain high surface resistivity practically all exposed insulation is given a very smooth or high-glaze finish.

The electrical conductor carrying the electric current through the insulation to one of the spark-gap terminals should

have low electrical resistivity and high heat resistance or high melting point. These characteristics are as follows for the most common commercial materials:

Material.	Melting point. Degrees C.	Degrees F.	Resistivity Ohm-mil-feet.	Max. working temp. Degrees C.
Nickel,	1,450	2,647	64.3	540
Iron,	1,600	2,912	59.9	.....
Copper,	1,083	1,892	10.37	260

Platinum has characteristics which make it the most desirable, but its cost is prohibitive.

The other terminal of the spark gap is grounded and is a part of the spark-plug casing or shell which is screwed into place on the cylinder. This terminal consists of single or multiple prongs secured to the spark-plug casing. It is much better to have the spark-gap terminal integral with the casing, either of same piece of metal or welded, than to have it joined mechanically, because of loss of heat conductivity through a mechanical joint. The greater the heat conductivity away from the spark gap, the greater the protection against overheating the spark-gap terminals or the insulation which may, as previously noted, cause pre-ignition, and which does result in rapid wear. The enclosed type of spark plug provides a spark-gap terminal integral with plug casing, and consequently provides good heat conduction from the spark gap. It also partially protects the insulation from the high temperature of combustion. In the enclosed type of spark plug the plug casing is extended down to the spark gap, which consists of a circular air gap between the conductor and the periphery of a hole in the closed end of the plug casing. Frequently the casing is cut away to permit access of combustion charge to both sides of spark gap and to furnish passage for flame propagation at ignition.

The screw-thread surface on the plug casing and in spark-plug seat in cylinder must be in good mechanical contact, not only to prevent escape of gases but also to provide adequate

contacting surface for heat conduction. Heat conduction across surfaces in mechanical contact is measurably decreased. Lucke comments as follows:

"Conductivity beyond the boundaries of a body is known to suffer a rapid decrease or heat flow to encounter a resistance through joints in metal bars or between plates at point of contact. Boiler plates offer appreciable resistance and boiler seams are forbidden in contact with fires by certain inspection laws, because experience shows the plates frequently burn, which they would not do if there were not a large joint resistance. Most carefully made, accurately fitted joints in experimental bars, in which there could not be over one ten-thousandth of an inch air layer, gave measurable joint resistance, smaller, of course, than a bad joint."

Carefully machined screw threads are more important for heat conduction than for making a gastight joint or electrical contact. In service if the spark plug is hotter to the touch than adjacent parts of cylinder, it may safely be assumed that heat conduction from the plug to the cylinder is poor and, unless remedied, the life of the plug will be appreciably shortened. If the cylinder near the spark plug is hotter than in a similar location on a different diameter, it is safe to assume that the access of cooling water to this part of cylinder jacket is retarded. Probable causes are displacement of core in casting, deposit of scale after some time in use with salt cooling water, deposit of waste or dirt at this locality in cylinder jacket.

In numerous cases the ignition fails, although the magneto tests out satisfactorily; the spark plugs are blamed without further investigation. That particular brand of spark plugs is worthless. Others are tried and eventually one brand is found which lasts longer than the others; but it is extremely probable that this brand does not last nearly as long as it should.

Short life or failure of any brand of spark plug in any engine should be carefully investigated before a conclusion is warranted that that make of spark plug is worthless. If the insulation is intact mechanically and electrically, and the

plug has operated for a short time, it will generally be found that the heat conditions are responsible for the short life. A more expensive plug may last longer, but its life will be much shorter than when operating under good conditions.

To get good service from spark plugs good conditions must surround the plug in operation.

Practically all commercial brands of spark plug will operate for varying periods in a water-cooled gasoline engine. The difference in the various brands being the length of service before points are burned out or the insulation is cracked in handling. Care in handling and no overheating in operation will materially increase the life of any spark plug.

To cover the points cited above in the general discussion of spark plugs the following specifications were prepared:

Material and Workmanship.—The plugs shall be the best material and workmanship, suitable for use in high-speed, high-compression, water-cooled gasoline engines, operating at from 1,000 to 1,200 r.p.m.

Types and Sizes.—Spark plugs shall be of the ½-inch pipe-thread type or the ⅝-inch A.L.A.M. standard, 18 threads to the inch; type, medium length.

Gaskets.—All ⅝-inch A.L.A.M. 18-thread standard plugs shall be fitted with a copper asbestos gasket.

Construction.—(*a*) Threading.—The threads shall be carefully cut in accordance with best commercial practice. With the plug in place, good mechanical contact shall be made through the thread between the plug shell and the spark-plug boss, in order that there may be good heat conduction between the spark plug and its seat.

(*b*) Insulation.—Insulation shall be of "Steatite" or equivalent material, having high electrical resistance and mechanical durability where subjected to high temperatures and to the action of oil and water spray, such as is encountered in the operation of motor boats in the service. Mica layer insulation, unless protected from the action of oil, will not be considered.

(*c*) Washers.—Plugs of the gland type shall be fitted with

suitable washers on both sides of the insulation between the gland and plug casing in such manner as to make a gastight joint and to protect the insulation from breakage where the gland is screwed tightly on its seat.

(*d*) The sparking points shall be integral with the conductor and the plug casing; mechanically attached sparking points are not satisfactory. The plug casing shall be of such form as (1) to furnish maximum heat conduction from spark gap; (2) protect insulation from radiated heat of combustion; (3) prevent falling of insulation into cylinder; (4) furnish access of spark gap to combustion charge and for flame propagation.

Tests.—(*a*) Plugs when assembled ready for installation in an engine shall be heated in an oil bath to a temperature of 300 degrees F., then immediately on removal passed through a spray of cool water and allowed to cool in the atmosphere.

(*b*) Plugs shall then be installed in a high-speed, high-compression, water-cooled gasoline engine, and the engine operated for one hour at maximum-designed revolutions and power. On the completion of the above tests the plugs shall be removed from the engine and examined for wear of points or other damage. The above test will be made on standard types of plugs at the Norfolk Yard, and no make will be considered acceptable under these specifications which has not satisfactorily passed this test.

Any suggestions for change in these specifications, with reasons therefor, will be most welcome.

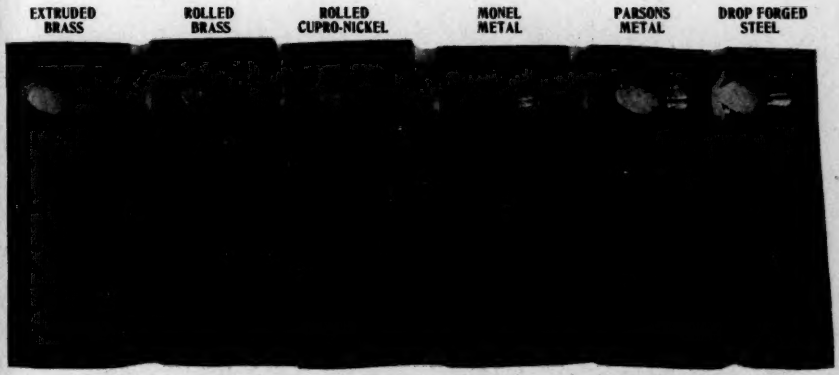
EROSIVE EFFECT OF STEAM ON TURBINE-BLADING MATERIAL.

By Lieutenant (J. G.) T. J. Keleher, U. S. N.

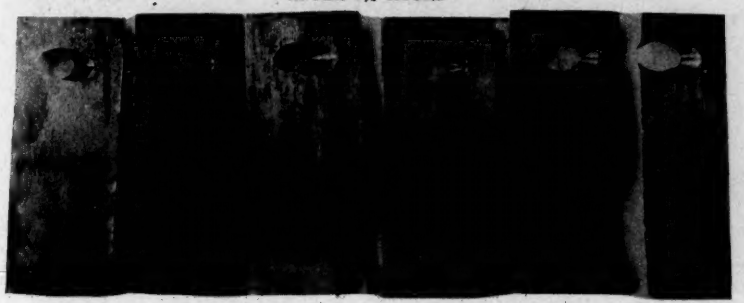
In the summer course of the Post Graduate Department of the Naval Academy an investigation of the erosive effect of steam on turbine-blading material was taken up as a research problem.

The apparatus used was a brass box, 9 inches × 9 inches × 7 inches, which acted as an exhaust chamber and contained the blade holders and blades, which were stationary and placed at an angle of 10 degrees to the nozzles in order to avoid the spattering effect. On the front of the box was a steam chest containing expanding nozzles designed for a hundred pounds gage pressure and twenty-seven-inch vacuum. A throttling calorimeter was used for the purpose of obtaining the quality of the steam.

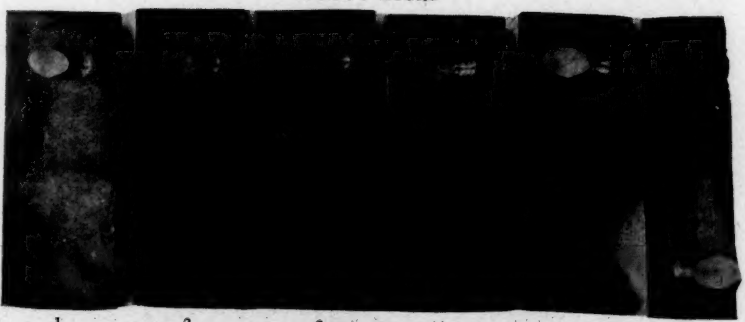
Extruded brass, rolled brass, rolled cupro-nickel, monel metal, Parsons metal and dropped forged steel were tested. The tests conducted were preliminary in their nature and intended to try out the efficiency of the apparatus. They will be followed next summer by tests at different steam velocities and with varying qualities of steam and degrees of superheat. Due to difficulty in obtaining the blading material, there were certain dissimilarities in the dimensions of the pieces tested, particularly in the case of the steel specimens. Inasmuch as the erosion is principally on the entrance edge of the blading, these discrepancies in blade width and thickness vitiate the weight losses when determined as percentages of the original weights of the specimens. The results of the preliminary tests are, however, so striking, as shown in the photographs, that it is considered that they may be sufficiently interesting



AFTER 3½ HOURS

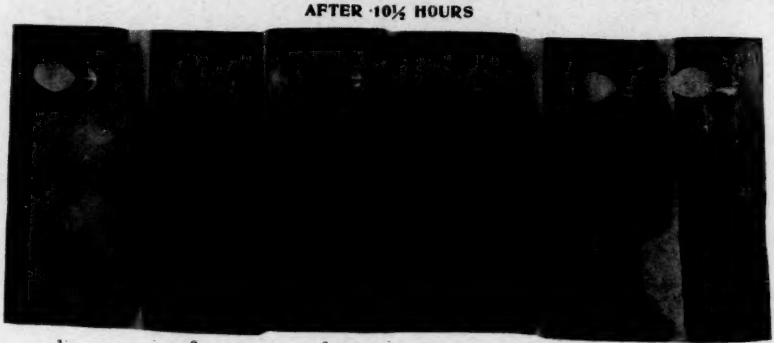


AFTER 7 HOURS



1 2 3 4 5 6

AFTER 10½ HOURS



1 2 3 4 5 6

to warrant publication at this time. Examining the table of weight losses it appears that extruded brass stood up best under the 3,400 foot-second velocity with steam quality of about 87 per cent., having a percentage of loss of 0.121, monel following with 0.273 and steel with 0.386. It must be stated, however, that the comparison between steel and the others is hardly a just one, for the reason that its width was less and its thickness considerably less. Rolled brass, cupro-nickel and Parsons metal did not compare at all favorably with the others. It was not expected that the Parsons metal would stand up under such a severe test, but it suffered so much in comparison with all the others that the result is interesting. In general, there appears to have been no particular uniformity in the amount of erosion during the different periods, although the percentage loss per period of cupro-nickel and Parsons metal reduced more or less uniformly.

Name.	Grams, original weight.	Inch, original width.	Weight. Per cent. loss 1st 3½ hours.	Weight. Per cent. loss 2d 3½ hours.	Weight. Per cent. loss 3d 3½ hours.	Weight, final. Per cent. loss, 10½ hours.
Extruded brass.....	7.0135	0.6015	0.07	0.02	0.03	0.121
Rolled brass.....	8.0090	0.5935	0.63	0.47	0.53	1.610
Rolled cupro-nickel....	9.4925	0.6342	0.87	0.81	0.77	2.435
Monel	8.5951	0.6224	0.01	0.15	0.12	0.273
Parsons	5.6835	0.6021	2.46	2.03	1.04	5.435
Steel.....	3.4955	0.4584	0.21	0.05	0.13	0.386

Run No.	Steam pressure, lbs. gage.	Vacuum, inches.	Steam quality.	Quality at blade entrance.	Velocity, foot-seconds.
1	100	22.7	99.28	87.40	3,420
2	100	22.6	99.00	87.15	3,410
3	100	22.8	99.06	87.20	3,415

Examining the photographs, which were taken at about two diameters, it is interesting to note on the photograph taken after 3½ hours the saw edges of the rolled brass and monel metal, and in particular the long points of the cupro-nickel, which, it would appear, are the result of lack of uniformity in the structure of the metals. On the next two photographs the saw edge is more apparent in the monel-metal, and in the last the steel begins to develop a similar edge.

CARE AND OPERATION OF ICE MACHINES.*

By LIEUTENANT COMMANDER J. O. RICHARDSON, U. S. NAVY, MEMBER.

DENSE-AIR MACHINES.

OPERATION.

Principle.—The operation of the machine consists in drawing in air from the system and compressing it to three times its absolute pressure. The work done on the air in compressing it heats it, and it is then passed through the cooling coils, where the circulating water and the cool return air extract the heat of compression before it enters the valve chest of the expander cylinder. In the expander cylinder the air expands doing work, thereby losing heat, so that it is discharged at a very low temperature, usually about one hundred degrees below the temperature at which it entered the expander cylinder, when this is about sixty degrees. The number of degrees of reduction of temperature is somewhat greater when the incoming air is warmer and somewhat less when its temperature is much below sixty degrees.

Starting.—If the machine is new and is to be started for the first time, it will be necessary to see that the system is clear of sand and scale, as any hard substance in the system will cause endless trouble by cutting the valves, valve seats, cylinders and piston packing. The parts of the machine carrying air and the whole system of piping should be blown out with air from the ship's air line.

Before starting the machine see that the valves on the suc-

*This article is a compilation of information received from officers, manufacturers, text-books and other sources.

tion and discharge lines to the circulating pump are open, the by-pass valve open, the main valves on the cold air and return air closed, the cylinder drains open, the valves on the hot-air blow line to the expander cylinder closed, and the drain valves on the expander cylinder and the pet cocks on the traps open. Have all bearings properly lubricated, jack the machine over by hand and start engine slowly after opening exhaust valve. See that circulating water is being supplied. Close steam-cylinder drains. When the discharge, from the drain valves on the expander and the pet cocks on the traps, is free of oil and moisture, close them and gradually build up the pressure to 125 pounds on the compressor. Open the sight-feed lubricators of the compressor and expander cylinders.

When a pressure of 125 pounds is reached blow down to 100 pounds through the drain on oil trap and expander drain cocks, and while the machine is building up the pressure open the pet cocks on the traps and the expander drain valves at frequent intervals, and at each opening keep them open until the discharge is free of oil and moisture. When the pressure has been built up to about 65 pounds on the expander and 235 pounds on the compressor cylinder, cut the machine in on the system by opening the valves on the cold-air and return-air lines, and closing the by-pass valve.

Speed.—The speed of the machines for every-day service may be anywhere from 60 to 100 revolutions per minute for the two and three-ton machines and from 75 to 120 revolutions for the smaller ones. For short periods the larger machines may be run up to 120 revolutions per minute and the smaller ones to 140 revolutions, but the normal speed, if the machine and system are in good condition, should be 60 for the larger machines and 75 for the smaller ones, and if the meat in the cold-storage rooms is well frozen and the temperature can be kept below freezing point with a slower speed, the machines should be run at as low a speed as practicable.

Pressures.—Within certain limits the pressure carried has little effect upon the efficiency of the machine so long as the

high pressure is approximately three times the low pressure, when these are expressed in absolute pressures. It is the correct ratio of pressures and the circulation of the air in the system which counts for efficiency rather than high pressures, so that with a correct pressure ratio low pressures and high speed will give better economy than high pressures and low speed. For customary service, pressures of 65 to 70 pounds per gage on low pressure and 230 to 245 pounds per gage on high pressure with a moderate speed should be used, but for maximum capacity the pressures should be high and the speed high.

Cylinder Lubrication.—It is of the utmost importance that the oil used for internal lubrication and for the rods should be the oil that is especially provided for that purpose. It is a good plan to mark the oil cans or distinguish them in some way so that there will be little chance of the oil for bearings being used by mistake for internal lubrication.

For internal lubrication about five or six drops of oil per minute for the compressor cylinder and none for the expander is sufficient, but the manufacturers recommend about three drops of oil per minute for the expander cylinder. It is desirable that the amount of oil used for internal lubrication be reduced to a minimum consistent with satisfactory lubrication, because the oil used is carried over into the system and forms a coating on the inside of the pipes which reduces their conductivity. On some ships using no oil for the expander cylinder it has been found advantageous to use a few drops of oil in the primer pump two or three times a day.

Lubrication of Piston Rods and Valve Stems.—By means of the oil cups on the piston rod and valve-stem stuffing boxes about two drops of oil per minute should be dropped into the stuffing boxes, but if the packing of the rods and stems is in good condition and the speed of the machine not over 60 revolutions per minute, no lubrication of the piston rods and valve stems is necessary, as the oil in the air affords sufficient

lubrication. On some ships it is the practice to use the lubricator only on the H.P. piston rod.

Lubrication of Bearings.—For lubricating the bearings about 4 or 5 drops of oil per minute is generally used, but the amount used depends upon the condition of the bearings and the speed of the machine.

Blowing Down.—Once a day it is necessary to clean the machine by heating it up and blowing out all the oil and ice deposits. This is done as follows: While the machine is running slowly and the compressor pressure has dropped to 150 pounds, the by-pass valve on the line from the oil trap to the return-air line is opened, the main valves on the cold-air line and the return-air line are closed, the valve on the hot-air blow line from the compressor to the expander is opened, and then steam is turned on the jacket of the oil trap very slowly and the drain from the jacket opened. Run this way for about thirty minutes, frequently opening the pet cock on the oil trap and the drain valves on the expander so as to remove all the oil and moisture. Then shut off the hot-air blow and the jacket steam and run the machine on the by-pass until it is certain that the air from the expander cylinder is cold enough, then cut the machine in on the system, closing the by-pass.

In spite of the proper draining of the moisture trap a certain amount of moisture will get into the expander; therefore it is desirable to open the drain valves on the expander and the traps about once an hour and blow out the oil and moisture. On some ships it is the practice to leave the cock on the primer-pump trap slightly open at all times in order to drain the moisture out of the newly supplied air. If the amount of oil used for internal lubrication has been reduced to a minimum and the drains on the expander and the oil trap opened for a few minutes each hour, it is practicable to reduce the blowing down to once every other day.

Piston-Rod and Valve-Stem Packing.—The packing of the piston rods and valve stems consists of a few rings of metallic packing, then a hollow oiling ring, then a few turns of L.P.

spiral packing. The setting of a definite regular time for repacking piston rods and valve stems will prevent troubles and shut-downs; therefore, it is recommended that the metallic packing be examined every two months to see that ends are not butting. At this time the soft packing should be renewed, using L.P. packing, as asbestos packing will score the rods if used in stuffing boxes of the air cylinders. In replacing this packing it is absolutely necessary to place the oiling ring in the correct position opposite the hole for the oil pipe, otherwise trouble will be experienced with hot rods and burned packing. The stuffing-box glands should be set up a little more than hand tight and great care should be taken to see that excessive friction is not caused by setting up too hard on these glands. The expander piston rod should run cool at all times, and if this rod warms up the packing should be overhauled and renewed, if necessary. Leaks around the stuffing boxes may be discovered by swabbing the rods with oil, and if a very little setting up on the glands does not stop the leakage it is far better to overhaul and renew the packing than to overload the machine with useless friction and run a chance of heating the rods. On one ship, with an electric-driven three-ton machine, the stuffing boxes were set up so hard that it required 15 H.P. to run the machine at 60 r.p.m. with no pressure on the system.

Packing of Expander and Compressor Pistons.—The pistons of the expander and compressor cylinder are packed with leathers or cast-iron rings. When packed with leathers those in the compressor usually last much longer than those in the expander cylinder. The expander leathers are often cut by ice chips formed in the cylinder due to the low temperature in this cylinder, but they should last about eight to ten weeks. In overhauling, it is a good plan to turn the expander leathers around so that the same part of the leather is not exposed to the most severe conditions at the cylinder ports. Much time will be saved if a former is used to form new leathers before they are installed, but if this is not used it is a good plan to

insert the first new leather in the rear end of the piston, and in a day or two, when this leather is formed, transfer it to the crank end of the piston and put a new leather in the rear end.

All of the late dense-air ice machines have cast-iron rings on both the compressor and expander cylinder.

Oiling Walls of Expander Cylinder.—The top side of the bore of the expander cylinder will rust very quickly after the machine is shut down; therefore, before shutting down for a long period a little extra oil should be fed into this cylinder. It is good practice to remove the cylinder head, wipe out and oil the cylinder walls if the machine is to be idle for a week or more.

Circulating Water.—The constant supply of an adequate amount of cooling water is of vital importance because the stoppage of the circulating water for only a few minutes while the machine is in operation may result in the scoring of the compressor and expander valves and the burning of the piston leathers.

It is a good plan to have the machine so connected that circulating water may be taken from the flushing system.

Draining Coils of System.—When the machines have been shut down for some time the cooling coils in the cold rooms will be thawed out and should be drained of any contained moisture and oil. These coils should not be thawed out or blown out with steam, as it is liable to start leaks, but should be blown out with air from the ship's air lines.

Cleaning Out the Ice-Making Box.—The oil in the cold air will gradually cover the inside surface of the ice-making box and reduce the conductivity of the walls, so that it is good practice to blow out the box with hot air or low-pressure steam when the machine is shut down for some time. Some ships make a practice of boiling out the ice box when the plant is given a thorough overhaul.

Washing Out the Cold-Storage Rooms.—The cold-storage rooms should be washed out and thoroughly cleaned at least

once every three months, as they will soon have a very disagreeable odor due to the gradual accumulation of blood and small pieces of meat.

Leaks in Ice Cans.—The ice cans should be frequently examined for leaks, as a small leak will render the ice very disagreeable to the taste.

Brine.—The brine for the ice-making box is best prepared by filling a bucket half full of crushed chloride of calcium, then filling the bucket with water and dissolving the chemical. Using hot water and stirring the mixture will quicken the process. The solution should be approximately a 20 per cent. solution, that is, 20 pounds of chloride of calcium to 80 pounds of water. A stronger solution is unnecessary, as the freezing point of this solution is 5 degrees F. The greater the quantity of chloride of calcium in the solution, the lower the specific heat, the less its heat-carrying power and the greater the tendency to deposit on the walls of the box or in the pipes in brine-circulating systems.

ADJUSTMENTS.

Alignment.—The cylinders should line up at right angles to the crank shaft with their center lines parallel to the guides, and in practically every machine the cylinders will have been so installed, and it should be unnecessary to check up this alignment unless excessive trouble is experienced with piston-rod packing and hot bearings.

The crosshead slipper is subject to wear, and unless it is of sufficient thickness to hold the piston rod in the center of its stuffing box excessive trouble will be experienced with the piston-rod packing. To determine whether or not the piston rod moves in the axis of the cylinder, remove the gland, withdraw the packing and caliper the distance between the rod and the stuffing box with the piston at each end of its stroke; if the piston rod is found high or low in the stuffing box, correct this by removing or adding liners back of the crosshead

slipper so as to lower or raise the crosshead end of the piston rod.

Adjustment of Bearings.—The method of scraping and fitting the bearings is the same as for other bearings of this size and type, and the clearances must be governed by the condition of the journals and the alignment and the size of the machine. With journals in good condition the main bearings should be adjusted by taking leads so as to give a clearance of about .005 inch.

The crosshead bearings should be adjusted so that the connecting rod will swing freely, by first setting up on the gib until the brasses touch the pin and then slacking back a small amount and trying the swing of the connecting rod.

The crank bearings are adjusted by taking leads so as to give a clearance of about .005 inch.

Fitting Crosshead Slipper and Guides.—The crosshead slipper and guides are scraped to a surface plate and adjusted so that the crosshead will slide freely, usually with a clearance of about .004 inch.

Fitting Bushings of Valve Gear.—The bushings on the rocker arms of the valve gears should not be set up without disconnecting one end of rod and swinging it to see that they are not too tight. These adjustments are made with a set screw, and, if not carefully made, may be the cause of much trouble.

Fitting Eccentric Straps.—The eccentric straps should be adjusted by swinging, in preference to taking leads, as the straps are easily sprung.

Clearance of Pistons.—The clearance of the pistons of the compressor and expander is only one-eighth of an inch. On account of this small piston clearance, care should be exercised, when adjusting bearings, to see that the clearance is the same at both ends; also, when overhauling or renewing piston leathers, to see that the piston rod does not unscrew from the crosshead. A tram should be made and marks properly made

on the crosshead and the piston rod near the crosshead for checking up the position of the piston rod.

Clearance of Primer-Pump Plunger.—The clearance of the plunger of the primer pump at the end of its compression stroke should be a scant sixteenth of an inch, and may be as small as one thirty-second. If set too close the plunger is liable to expand when hot and may strike. The clearance of this plunger has an important effect upon the efficient operation of the machine and should be very small, if there are many air leaks in the machine or system, but, if there are few leaks, the clearance should be increased so that the relief valve will not continually lift at the end of the compression stroke.

Setting the Slide Valves.—The setting of the slide valves is similar to that of setting a slide valve on any steam engine, except with additional details due to the design of the valve chest and the valves.

Putting the Crank on the Center.—In setting the slide valves of any cylinder it is necessary to put the corresponding crank on the dead center, so that if a tram and center marks are not already available it is necessary to make a tram and punch the center marks. To make a tram secure, a steel rod about three-eighths inch in diameter and of sufficient length when formed to reach from some convenient point on the bed plate to the face of the flywheel. Grind both ends to a point and bend one end, or both, if necessary, so that points will drop into center-punch marks to be made on face of flywheel and on bed plate.

When tram is ready place a deep center-punch mark on the bed plate for the permanent use of the tram. Jack the machine until the crosshead, whose crank is to be placed on center, is about two inches from end of its stroke, scribe a mark across the crosshead and crosshead guide and at the same time, with one end of the tram in center-punch mark on the bed plate, scribe a light mark on the face of the flywheel with the other end of the tram; then jack the crank over the center until the marks on the crosshead and crosshead guide come in line,

then with tram scribe a light mark on face of flywheel as before. This gives two tram marks on the face of the flywheel, each made when the crank was the same distance from the dead center; bisect the distance between these two marks and place a deep center-punch mark at this central point; jack the machine until the tram point drops into this center-punch mark when the other tram point is held in the mark on the bed place; the crank will then be on the dead center. This operation should be repeated until marks are placed for both dead centers for all three cranks.

Setting Lower Valve of Expander Cylinder.—With both upper and lower slide valve removed from the valve chest, mark the valve-chest walls with chalk and, using a small straight edge and a square, with a scriber transfer the ports in the valve seat to the walls of the valve chest. With a square and a scriber transfer the valve admission ports from the bottom to the top of the valve. Replace the lower valve and place a straight edge on the top of the valve and with a scriber draw a line on the valve-chest wall parallel with valve seat and intersecting the previously drawn vertical lines which represent the ports in the valve seat, and mark the intersections with a center punch. Put the expander crank on the dead center and by means of the adjusting nuts set the valve by observing the port lines on top of the valve and the valve-seat-port marks on the valve-chest walls so that it will have a lead of 1-32 or 1-16 of an inch, depending upon the size of the machine as shown in the table. Place the expander crank on the other dead center and see that the lead is the same, then set up on the adjusting nuts and lock nuts so as to leave a clearance of about .002 inch between the faces of adjusting nuts and the valve. This clearance is sufficient to allow the valve to seat properly and not enough to cause a knock.

Setting Upper Valve of Expander Cylinder.—Replace the upper valve and mark the stroke of the expander piston on the expander crosshead guide, then jack the machine until the upper valve begins to cut off, and measure on the guide

the distance the crosshead has traveled from the end of its stroke, which should be from 3¼ to 6¼ inches, depending on the size of the machine as given in the table; repeat this operation for the other end of the valve and, if the measured distances of crosshead travel are not equal, shift the valve by means of the adjusting nuts until these distances are equalized, then set up on the lock nuts, and the valve setting for this cylinder is completed.

Size.	Type.	Steam Cylinder.		Expander Cylinder.		Compressor Cylinder.	
		Lower valve lead.	Upper valve closes.	Lower valve lead.	Upper valve closes.	Lower valve lead.	Upper valve opens.
					inches.		inches.
½	Vert.	Notch	...	1/16	3¼	3/32 Lap	4¼
1	Vert.	Notch	...	1/32	3¼	1/16 Lap	4⅜
1	Hor.	3/32	...	1/16	4	1/16 Lap	5¼
2	Hor.	Notch	...	1/16	5¼	1/16 Lap	6¼
3	Hor.	1/32 + Notch	From 4 to 8 ins.	3/32	6¼	Line and Line.	6¼

Setting Lower Valve of Compressor Cylinder.—The procedure in setting the lower valve is the same as in setting the lower valve of the expander cylinder, except that this valve has inside admission and the valve is given a lap instead of a lead, the amount, which should be the same at each end, being given in the table for each size of machine. Since the construction of this valve does not give a surface on top to which the admission port may be transferred, a thin piece of wood or heavy cardboard must be secured on top of the valve, to the top of which the admission port of the valve is transferred for use in setting the valve.

Setting Upper Valve of Compressor Cylinder.—The procedure in setting the upper valve is the same as in setting the upper valve of the expander cylinder, except that this valve should just begin to open when the jacking is stopped for the

measurement of the distance the crosshead has traveled, and this distance should be from 4¼ to 6¾ inches, depending on the size of the machine as given in the table.

Setting of Valves of Steam Cylinder.—The setting of the steam valves is the same as on any steam engine, the position of the valve being given in the table. If the steam cylinder is fitted with a riding cut-off valve, the procedure in setting this valve is the same as for the upper valve of the expander cylinder, the data for setting this valve being found in the table.

Marking Position of Valves.—After the valves are once properly set, their position should be marked with reference to a fixed point on the valve-chest wall. This will save time when the valves are removed for examination or refitting, as they may be replaced by these marks instead of resetting them. The valves and the valve seat should be well lubricated before the valves are replaced.

Taking Indicator Cards.—Indicator cards taken from the expander and the compressor cylinder will show whether or not the valves are properly set and functioning properly, and are of very great value in locating the cause of inefficient operation if it is due to leaking or improperly set valves.

Adjustment of Primer-Pump Valves.—The valves of the primer pump are very important parts of the machine and should be carefully adjusted. The suction valve is fitted with a comparatively weak spring, the tension of which is adjusted by a nut and lock nut on the valve stem. The tension on this spring should be just enough to insure that the valve is held to its seat, as any greater tension may prevent the valve lifting on the suction stroke and any less would cause the valve to remain unseated with the consequent loss of air on the first part of the compression stroke. The usual lift of this valve is from 1-16 inch to 3-32 inch. On the larger machines the operator can tell whether or not the suction valve is functioning properly by watching it, and, as a rule, when working properly it makes a light chattering noise. On the two-ton

and smaller machines the operator, by placing his fingers on the suction holes in the primer-pump plunger, can tell whether or not the pump is taking air.

The lift of the primer-pump discharge valve is limited by a stop piece over the valve, the usual lift being from 1-32 inch to 3-64 inch. This valve should be carefully fitted because, if it leaks, the primer pump is ineffective and the high-pressure air leaking into the pump barrel will keep the suction valve seated, thereby giving the impression that the adjustment of the suction-valve spring is faulty. The valve spring is usually made of steel and frequently corrodes and breaks. Bronze springs give good service and are not so liable to break. This valve should be carefully ground in; the usual method of testing one is to see that no shoulder exists, then mark seat and disc by drawing a lead pencil across seat, enter disc and turn same carefully against the seat and examine the seat to see if the pencil marks are cut. If the disc is allowed to wabble while turning, it will give a false impression, if the valve seat is worn slightly oval. If this valve is not properly fitted it is liable to stick when it expands under the influence of the heat generated by the compression of the air.

SUGGESTIONS.

Connection to Ship's Air Line.—If a connection is installed between the ship's air-pressure line and the discharge from the primer pump, the system may be quickly filled with air, so that much time may be saved on starting up or the machine may be run with the primer pump not operating properly. If such a connection is made a drain should be fitted to the connection near the ice machine and care taken to thoroughly drain all the moisture from the connection before admitting any air to the refrigerating system.

Drain on Steam Line to Trap.—A drain valve should always be fitted in the steam line to the jacket of the cold-air trap in order that any water may be drained out of this line before use and to make certain that the cut-off valve is not leaking

steam into the jacket of the trap while the machine is running.

Drain on Cold-Air Piping.—If drains are fitted to each line of piping beyond the machine it is possible to tell whether any valve in the piping system is leaking without disconnecting any of the piping.

Drain on Ice-Making Box.—Drains should be fitted on the bottom of the ice-making box, as some moisture is almost certain to collect in the box.

Drain on Manifolds.—On some ships drains have been fitted to valve manifolds in the refrigeration system in order to drain the moisture that frequently collects there.

Drain on Re-cooler.—On some ships a drain has been fitted to the re-cooler near the bottom of the low-pressure head for use in draining out any oil that might collect in the re-cooler.

Relief Valve on Ice-Making Box.—Good practice requires the installation of a relief valve on the ice-making box, as this is the weakest part of the system and several of these boxes have been cracked by excessive pressure.

Wire-Gauze Screen over Primer-Pump Suction.—A wire-gauze screen should be placed over the suction of the primer pump in order to prevent the possible drawing into the system of dirt, waste, or other foreign matter.

Ice-Making Box Used as a Trap.—When not making ice it is a good idea to close only the discharge valve from the ice-making box, leaving the inlet valve open. Under these conditions the ice-making box is used as an oil and moisture trap, and it should be drained from time to time.

Reverse Connections to Ice-Making Box.—In tropical waters, on ships with small ice machine capacity, where the machine is required most of the time directly on the cold storage, it has been found advantageous to fit cross connections to the ice-making box so that return air from the cold-storage system can be used on this box. With this connection it is possible to chill the water in the ice cans before putting the cold air di-

rectly on the ice-making box, and so reduce the time of operation under the latter conditions.

Cool Circulating Water in the Tropics.—In the tropics it frequently happens that the surface water is warmer than the water below, and some ships have rigged a suction hose over the side so that the cooler water may be used for circulating water, thereby increasing the capacity of the ice machine.

Filling Ice Cans.—It is good practice to fit the end of the ice-can filling hose with a vertical check valve so that the pressing of the valve stem on the bottom of the can will open the valve and fill the can from the bottom, driving out the air and reducing the amount of air which is usually mixed with the water in filling the cans.

Blower in Cold-Storage Room.—The time required to reduce the temperature of a cold-storage room can be reduced and the efficiency of the plant increased by installing a blower in the cold-storage room so that it discharges against the cold-air piping and sets up a circulation of air throughout the room. On the *Paducah* an installation of this kind is made as follows: Motor is installed on bulkhead outside of storage room. Speed reduction is obtained by inserting a 32-candlepower lamp in series on supply line to motor. Fan and casing were disconnected from shaft of motor and installed in the storage room. Fan is installed on a long shaft passing through a galvanized-iron pipe fitted in hole drilled through storage-room bulkhead. Galvanized-iron pipe is made air and watertight by special fittings. Fan shaft is supported by ball bearings on storage-room end, and a stuffing box with flax packing is fitted at motor end, both the ball bearings and stuffing box being fitted in the galvanized pipe. The motor shaft and fan shaft are connected by a flexible coupling. The motor is shut down before entering storage room, and also whenever cold air is shut off for any purpose.

Re-cooler Made on Board Ship.—When no re-cooler is installed and trouble is experienced with the cold storage, a very efficient re-cooler can be constructed on board ship and

installed in about four hours. With circulating water over 80 degrees F., the *New Orleans* was unable to keep down the temperature of her cold storage, so a re-cooler was made for a one-ton machine by using a four-inch pipe about seven feet long. Heads were made of brass to form a tube sheet and screwed on each end of the pipe. Holes drilled into these heads to take condenser tubes. The condenser tubes were expanded on each end and ferrules driven into ends of tubes to stiffen them and keep them from working loose. The cooler was fashioned after a feed-water heater, the high-pressure air going through tubes, the flow being so that return air entered at top of shell, at same end where high-pressure air left re-cooler on its way to the expander. The return air left opposite end of re-cooler from top of shell and air from cooler entered tubes at this end. This caused the coldest air to come in contact with coldest surfaces. The cooling medium was brought close to the air to be cooled by using small tubes. This re-cooler is very efficient.

The cooler when complete was clamped to the deck beams over the ice machine and lagged. The pipes measured up, cut and threaded. The necessary valves and fittings were drawn out. Then the machine was shut down and the old pipes removed. The lines cut and valves inserted so that machine could be run as before in case the cooler failed. The connections were all made and the machine running within a few hours times. The result was that there was no trouble with the temperature of the cold storage. Afterwards a cross connection was fitted so that machine could be run on cold storage and return through ice box. When this was done there was no more trouble about making ice along the coast of Mexico.

Heater for Air Blow Out.—In blowing out the pipes of the cold-storage system heat will materially aid in clearing the system of oil, but the use of steam for blowing out the system is objectionable on account of the danger of starting leaks. Some ships use the machine itself with the hot-air blow line open to blow out the system, but this is dangerous on ac-

count of the tendency to overheat the machine. The best plan is to make a small heater like a bath-room heater and use air from the ship's compressed-air line for blowing out the system and steam on the heater for heating the air, as, in this way, the temperature of the air used for blowing out can be regulated.

Record of Spares.—A record of all spare parts, with their location, should be kept up to date and available in case of breakdown, as the saving of thousands of pounds of fresh provisions, besides the comfort and the health of the crew, may depend upon the quick repair of the machine.

TROUBLES.

Pressures Correct and Ratio Correct but Machine Not Effective.—If the machine maintains the correct pressure and the correct ratio of pressures but fails to maintain the usual low temperatures, the trouble is probably due to one of the following causes:

Insufficient circulating water;

Mud in cooler or compressor jacket;

Machine not clean and clear of oil and moisture;

Ice-making box and system not clean and clear of oil and moisture.

Insufficient Circulating Water.—Feel overboard-discharge pipe to see if it is warm and look over the side to see if there is an adequate discharge of circulating water. If the overboard-discharge pipe is warm or there appears to be insufficient circulating water, open the valve putting the flushing or fire pump on the circulating system, and if this does not immediately give sufficient cooling water stop the machine, as its operation for only a few minutes without circulating water will burn up the leathers and cut the compressor and expander valves.

Mud in Cooler or Compressor Jacket.—If there is sufficient circulating water, feel the ends of the cooler and the com-

pressor jacket. If either of these is warm it is due to a deposit of mud. Stop the machine, remove the cooler head and clean out the cooler. Trouble from this source is likely to be encountered when operating for any length of time in muddy water, as at Shanghai, Mare Island, New Orleans, or the Navy Yard, New York. Whenever a machine is given a thorough overhaul the cooler should be cleaned out, and, if much mud is found, the compressor jacket should also be cleaned out by washing out with clean water under a good pressure or by drawing the liner if the water does not remove the caked mud.

Machine or System Not Clean.—The rise in temperature due to these causes will be gradual and should not occur if the machine has been thoroughly blown down at regular intervals and the ice-making box and system blown out whenever opportunity offered, but if no other cause of the trouble is located the machine should be blown down as previously described. This should cause the temperature of the cold-air discharge from the expander to come down to the usual reading, and if trouble is still experienced it is due to oil and moisture in the ice-making box and in the system.

Loss of Pressure, the Ratio Between Pressures Remaining Correct.—If the machine loses its pressure or refuses to build up the pressure, the ratio between the high and the low pressure remaining correct, the trouble is probably due to one of the following causes:

Leaks around piston or valve rods;
Leaks in cooling coils;
Leaks in ice-making box;
Leaks in system;
Faulty action of primer pump.

Locating Leaks.—Cut the machine off the system and run it on short circuit; then if the pressure builds up there are no leaks in the machine.

Put the machine on the ice-making box, and if the pres-

sures are satisfactory the ice-making box is not leaking; then put the machine on the scuttle butt and observe the pressure; then on the cold-storage system and observe pressure. This method will show what part of the installation is leaking.

Leaks Around Piston and Valve Rods.—Leaks around the piston and valve rods may be discovered by swabbing the rods with oil and watching for air bubbles. If a very little setting up on the gland does not stop the leakage it is far better to overhaul and renew the packing than to overload the machine with useless friction and run a chance of heating the rod.

Leaks in Cooling Coils.—A pet cock should be installed on the top of the cooler; then, if the machine is running and the cooling coil is leaking, on opening the pet cock air will blow out. If the machine is not running, put an air pressure on the cooling coil, open the pet cock and close the valves on the sea-water circulating system and air will blow out of the pet cock if the coil is leaking. Using the last method it is possible by trying out to tell whether the main cooling coil or the primer-pump cooling coil is leaking.

Leaks in Ice-Making Box or System.—Leaks in the ice-making box and the system of piping may be located by covering them with soapy water and watching for air bubbles. Frequently when the ice-making box is leaking it will be found that after running on the ice-making box for some time ice will form over the leaks, stopping them, so that the ice-making box should be examined for leaks soon after turning on the cold air.

Faulty Action of Primer Pump.—To determine whether the primer pump is functioning properly, place the hand over the suction and see if the pump is taking air. Feel the primer-pump discharge pipe and, if it is not very warm, the action of the pump is faulty. On the three-ton machines watch the primer-pump suction valve and see if it is unseating and seating properly. A valve should be placed in the discharge line near the cooler; then, on closing this valve, the relief valve

should lift if the primer pump is operating satisfactorily. In case this pump is not operating properly, by closing this valve it is possible on the large machines to overhaul the primer pump-suction valve while the machine is in operation.

Loss of Pressure, the Ratio Between the Pressures Being Incorrect.—If the machine fails to maintain the correct pressure and the correct ratio between the high and the low pressure, the trouble is probably due to one of the following causes:

Leaky valves of the compressor cylinder;
Leaky valves of the expander cylinder;
Leaky compressor or expander leathers or packing rings;
Incorrect setting of compressor or expander valves;
Leak in re-cooler (return-air cooler).

Leaky Compressor Valves.—Stop the machine with pressure on the machine and system, close the valve on the expander inlet, then if the pressures equalize the valves on the compressor cylinder are leaking.

Leaky Expander Valves.—If the lower pressure is higher than it should be while the machine is in operation it indicates that the valves of the expander cylinder are leaking.

Leaky Compressor or Expander Leathers.—It is difficult to tell whether it is the expander or the compressor leathers or packing rings that are leaking, but, as a rule, the compressor leathers last three or four times as long as the expander leathers. Knowing the time of last renewal of the leathers, it is possible to determine which should be examined first. If there has been any trouble due to an insufficient supply of circulating water the compressor leathers should be examined first.

Incorrect Setting of the Valves.—The easiest way to determine whether or not the valves are correctly set is to take indicator cards. In fact, incorrectly set valves, leaking valves, and leaking piston leathers can all be located by indicator cards, and no instrument is of more value in operating one of these machines than an indicator. If a machine is in good condi-

tion the indicator card from the expander cylinder will approach very closely to a theoretically perfect card.

Leak in Re-cooler.—To determine whether the re-cooler is leaking, stop the machine with pressure on, then close the valve on the expander inlet and drain the low-pressure air from the system, open the re-cooler drain cock, and air will blow out if the re-cooler is leaking. If there is no drain cock on the re-cooler, one should be installed near the bottom of the low-pressure end for use in draining the re-cooler and testing it for leaks.

Stoppage in Discharge Pipe From Expander.—This will be noticed on the gage by a drop in pressure on system. To distinguish this trouble from faulty leathers on pistons, open by-pass valve. Should pressures become normal when by-pass is open it will indicate a stoppage in line to cold storage or ice box. Try to run on each separately, and if a normal pressure is not established on either it will indicate a stoppage nearer machine which will most likely be trap chocked.

The U. S. S. *New Orleans* had much trouble with the discharge air from expander, due to line freezing up. The most difficult stoppage to locate was that due to the pocket in expander-valve chest freezing up. This pocket is located under slide valve where port connects with discharge outlet. The trouble being in the machine, could not be located by running on the by-pass. It was indicated by a drop in pressure on system and an increase on compressor. The trouble was remedied as follows:

Blow down machine and thaw out, by using hot air from compressor. When hot air has been used about 30 minutes, connect air hose from compressors in engine room to bottom of trap and stop machine. Turn air into trap, having drains on expander open. Jack machine over a few times. This causes a strong flow of air in opposite directions and dislodges the oil and water collected in discharge port. There was trouble once after this was done, due to the thawing not being complete. After the machine had been in operation about two hours a sudden and almost complete stoppage in discharge

took place. To locate the cause the valves of expander were removed. When this was done a piece of ice was found lodged against the outlet.

A complete remedy for this was obtained when the machine was laid up for repairs. The cylinder was removed and a ⅜-inch drain pipe fitted so as to drain pocket formed by discharge port. Extra heavy nipple was fitted so that there would be no chance of it breaking off in an inaccessible place when cylinder was replaced. A pipe was run to connect, and an angle valve located at after end of cylinder where it was within easy reach. When the machine was in operation this pocket was drained out about twice each watch. No more trouble was experienced with stoppages of freezing line.

This trouble was not caused by allowing water to collect in the small trap on supplementary air line. It was only experienced on the west coast of Mexico, when the machine was being worked to its greatest freezing capacity. The circulating water is not cold enough to cause the moisture in make-up air supply to precipitate in trap. Most of the moisture was deposited in the expander. When a stoppage took place in the freezing line beyond trap it would be found at valve to ice box if machine had been running direct on cold storage, and at valve to cold storage if running on ice box.

The line stopped is easily located. When located, remove bonnet of valve and use a stiff wire or a packing hook to remove ice. It will be found in a mass of small crystals.

Gasket for Crank End of Cooler Improperly Cut.—The combined trap and cooler for discharge air from the primer pump is located on the head of the cooler nearest the crank end. There is a rib across the inside of this casting extending out flush with the face of the flange so that when in position the newly admitted hot air must pass near the head of the cooler through the space between it and this rib, which space is only the thickness of the gasket. On one ship, in renewing this gasket the new gasket was inadvertently cut with a cross piece in it, which was placed under this rib so that when

the machine was assembled it would not build up the pressure because the cross piece prevented the primer-pump air from entering the system. The trouble was finally located by admitting air from the ship's compressed-air line to the primer-pump discharge line and breaking the line from this trap; then, when no air issued from the trap, it was known that the stoppage was in the trap.

CARBONIC ANHYDRIDE (CO_2) MACHINES.

OPERATION.

Principle.—In this machine the refrigerant is carbonic anhydride (CO_2), a colorless, odorless, non-poisonous, non-explosive gas. The gas is drawn into the compressor cylinder from the system and compressed to 750 to 1,200 pounds per square inch, depending upon the temperature of the circulating water in use. The work done upon the gas in compressing it heats it, and the gas is then discharged from the compressor and passes to the condenser, where the circulating water, passing around the pipes, extracts the heat and condenses the gas into a liquid. The liquid CO_2 then passes to the liquid receiver. When a brine system is used the liquid CO_2 passes from the liquid receiver to the regulating (expansion) valve into the evaporator (brine tank) where the liquid vaporizes into a gas and expands, thereby producing a very low temperature. The pipes of the evaporator are surrounded by brine from which the gas extracts heat so that the brine is cooled to the desired temperature. From the evaporator the gas passes, through pipes and separators, to the compressor, and the cycle of operations has been completed. Where the term evaporator is used in this article it means the system of piping which in the brine tank or ice-making box is surrounded by brine. In the direct-expansion system brine is not used. Carbonic anhydride coils are placed in the scuttle butts, refrigerators or cold-storage rooms. The regulating or expansion valve is then close to the cooling coils and the liquid CO_2 passing

through the valve vaporizes and expands through the cooling coils and returns from them to the compressor.

Cleaning System of New Machine.—If the machine is new and is to be started for the first time it will be necessary to see that the parts of the system that carry the gas are thoroughly cleaned of all scale, dirt or other foreign matter. This can be done fairly well by blowing the pipes out with compressed air and by removing and cleaning all valves, but when a new machine is put in operation it must be carefully watched and thoroughly cleaned as needed, because any mill scale or dirt that is present will probably work into the suction and discharge valves of the compressor and cause much trouble from leaky valves.

Charging the Machine.—Before charging the system, remove the discharge valves, pour ice-machine oil into the compressor cylinder, fill the oil pump; on vertical compressors remove the cylinder head, and run the machine slowly for about two hours, using the oil pump at its maximum feed. While the machine is running all valves on the system should be opened wide. After the machine has been run for about two hours shut it down, replace the discharge valves and the cylinder head if it has been removed. It is now necessary to remove the air from the system. This is done by closing the regulating valve, opening all other valves and breaking the joint in the line to the regulating valve, then running the compressor to draw all the air out of the evaporator, CO_2 cooling coils and suction piping. Then stop the machine, close the discharge stop valve and partly charge the system as described later. After the system is partly charged open the discharge stop valve, run the machine for a few revolutions, blowing all the air out of the condenser, liquid receiver and piping, then close the discharge stop valve, remake the broken joint, open the discharge valve and complete the charging. A flask of CO_2 is now suspended, valve upwards, from a spring balance and connected by a copper pipe to the charging valve on the system. See that connections are tight. Note the weight of the charged

flask so that you can tell when it is empty and how much gas has been charged into the system. The steel flasks usually contain about 50 pounds of CO_2, and the number required to fill the system will have been obtained from the makers. Open the charging valve on the system and open very slowly the valve on the flask. When charging, carefully examine all joints as the pressure rises, using soap and water for the purpose. After the flask is half empty, warm it with hot water, being sure to warm the lower part of it, as any remaining CO_2 will be cold and in that part of the flask. When the flask is empty close the valve on the flask and the charging valve while the flask is warm.

Starting.—Before starting see that the circulating water is passing through the condenser, fill all oil cups and oil pump, see that the discharge stop valve on the compressor and all valves to the condenser are open, slack off on small gland nut on piston-rod end of large gland; start the machine slowly and open suction valve about one turn. Failure to open the discharge valve from the compressor before starting the machine will, in three or four strokes of the machine, cause the blowing out of the diaphragm on the safety valve with the accompanying loss of gas. When the machine is going see that a slight amount of oil, about two drops per minute, comes out of the gland around the compressor rod. If this gland is too loose gas will escape, and if too tight the rod will run hot. After the machine has been running three or four minutes open slowly the suction valve until it is wide open. Regulate the stroke of the oil pump so as to use a pump full of oil every six to eight hours. Refill the pump before it is empty.

After the machine is in operation a few minutes it will begin to build up the pressure on the condenser. The compressor cylinder should remain cold and the suction valve should become covered with ice. The discharge pipe from the compressor should be rather warmer than the hand can comfortably bear. If this pipe is not hot enough the regulating valve should be slightly closed, when the temperature will

quickly rise. If the compressor cylinder becomes warm the regulating valve should be opened slightly to increase the suction pressure.

Pressures.—The CO_2 gages on the condenser and the evaporator indicate on the inner circle, in black figures, the pressure, in atmospheres, and on the outer circle, in red figures, the corresponding temperatures of CO_2.

The pressure that should be carried on the condenser depends upon the temperature of the circulating water available. The lower the temperature of the circulating water the lower the pressure required.

The condenser pressure should be carried at about 10 atmospheres (one atmosphere being 14.7 pounds) above the pressure corresponding to the temperature of the circulating water in use. The pressure corresponding to a given temperature can be found in the following table:

Properties of Saturated Carbonic Acid Gas.

Temperature Fahr.	Pressure atmosphere.	Total heat B.t.u. above 32°.	Heat of liquid B.t.u. above 32°.	Latent heat of evaporation.	Weight of vapor, pounds per cubic foot.
90	77.0	.....	.....	.....	.....
80	68.0	104.0	63.0	41.0	17.5
70	60.5	103.9	44.0	60.0	13.1
60	52.5	103.6	29.4	74.0	10.6
50	46.2	103.2	17.6	85.6	8.7
40	40.0	102.8	7.5	95.0	7.0
30	34.5	102.2	—1.8	104.0	5.9
20	29.5	101.6	—10.0	111.0	5.0
10	25.0	100.9	—17 5	118.0	4.17
0	21.2	100.3	—24.0	124.0	3.5
—10	17.7	99.5	—30.9	130 0	2.9
—20	14.8	98.5	—36.5	134.0	2.45
—30	12.4	97.5	—41.5	140.0	2.0

For example, if the temperature of the circulating (sea) water is 70 degrees F. the pressure corresponding to this temperature is 60.5 atmospheres, and the condenser pressure should be about 70.5 atmospheres, when the plant is fully charged with gas. Any drop in this pressure, unless caused by a change

in the circulating water or the setting of the regulating valve, indicates a leak in the system.

The evaporator or suction pressure should be the pressure corresponding to a temperature of 10 to 15 degrees below the temperature of the brine leaving the evaporator. For example, if the brine leaves the evaporator at a temperature of 10 degrees F. the pressure on the evaporator should be that corresponding to 0 degree to —5 degrees F., or 21.2 to 19.5 atmospheres as shown by the table.

Circulating Water.—When the circulating water has a temperature of 60 degrees to 70 degrees F. a sufficient quantity of circulating water should be supplied to the condenser to secure a rise of 10 degrees to 15 degrees F. between the supply and discharge sea water. In other words, if the sea water is 65 degrees F. the circulating water discharge from the condenser should be between 75 degrees F. and 80 degrees F. If the temperature of the sea water is 80 degrees F. or above, more circulating water will be required, and the rise in the temperature of the water should not be more than about 50 degrees F.

Faulty Operation.—If the machine is not working properly, it may be due to one of the following causes:

1. Shortage of gas in the system;
2. Leaking valves;
3. Defective packing.

Insufficient Gas in System.—If the regulating valve cannot be adjusted so as to keep the compressor cylinder cold and the discharge pipe warm with the pressure correct, the trouble is probably due to insufficient gas. As a further test, close the regulating valve with the machine in operation, and if the evaporator gage falls rapidly and continuously the system is short of gas. If properly charged the evaporator gage should hardly move for about 15 or more revolutions. If the system be short of gas the machine will develop only a fraction of its cooling capacity. If there is insufficient gas or if in doubt on

this point add more gas as a 20 per cent. overcharge will do no harm. An overcharge of gas will be indicated by an increase in the condenser pressure above that normally carried.

Leaking Compressor Valves.—To test the work of the compressor close the regulating valve while the machine is running at normal speed. The evaporator (suction) pressure should be pumped down from about 25 atmospheres to 5 atmospheres in 200 revolutions. If it takes longer the compressor valves may be leaking or the piston rings or leather cups may be defective. If a suction valve is leaking it can be detected by listening carefully with the ear close to the bonnet. The gas can be heard hissing through the leaky valve on the discharge stroke. A leaky discharge valve on one end is indicated by an uneven vibration of the condenser (discharge) pressure. Feel the caps on the discharge valves and the one that is hottest is the leaky one.

In machines with the valve seatings making double joints, see that both the bonnet-joint ring (fiber or copper) and the valve-seat joint ring are equally compressed. If there is less impression on one of these rings than on the other add paper washers under the lighter one until the impression is equalized. Leakage at the bonnet joint will indicate itself outside, but at the valve-seat joint will not be perceptible except in reducing the work done by the machine.

Defective Rod or Piston Packing.—If the compressor valves are in good condition, sufficient gas in the system, and no leaks found, but the machine shows decreased capacity, the piston packing is probably worn and should be examined and new leathers or rings installed if necessary.

Lubrication.—It is very necessary to keep the interior of the machine well lubricated with good oil that will not thicken in zero temperature. Care should be taken not to use too much oil, as it will get into the cooling-coil pipes and, due to the very low temperature, congeal and gradually form a coating on the inside of the pipes. This coating of oil will greatly reduce the efficiency of the plant.

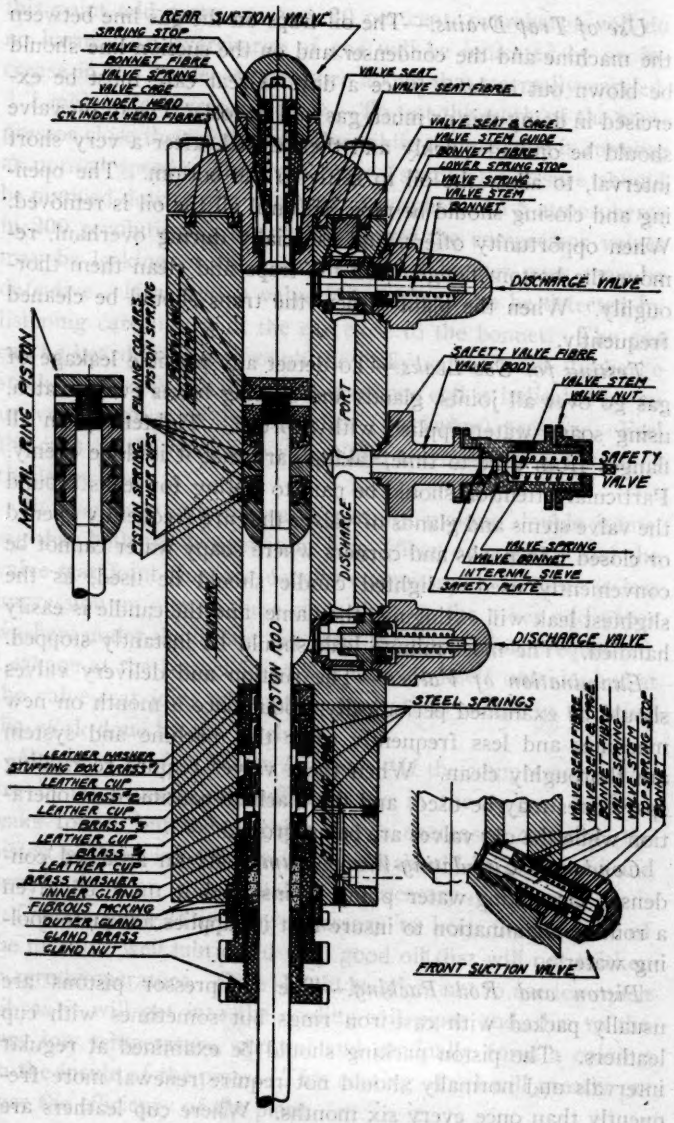
Use of Trap Drains.—The oil traps on the gas line between the machine and the condenser and on the suction line should be blown out at least twice a day. Great care must be exercised in doing this or much gas will be lost. The drain valve should be opened quickly and then closed, after a very short interval, to allow the oil to settle to the bottom. The opening and closing should be repeated until all the oil is removed. When opportunity offers, and especially during overhaul, remove the bottom flange from the traps and clean them thoroughly. When the plant is new the traps should be cleaned frequently.

Testing for Gas Leaks.—To detect any possible leakage of gas go over all joints, glands and stuffing boxes every watch, using soapy water applied with a brush. Tighten up on all flanges from time to time, taking care that it is done evenly. Particular attention should be paid to testing for leaks around the valve stems and glands of valves that are frequently opened or closed. In nooks and corners where soapy water cannot be conveniently used a lighted candle should be used, as the slightest leak will extinguish the flame, and the candle is easily handled. The most minute leak should be instantly stopped.

Examination of Valves.—The suction and delivery valves should be examined periodically, about once a month on new machines and less frequently after the machine and system are thoroughly clean. When these valves require regrinding spare ones may be used, and the machine continued in operation while the old valves are being ground.

Condenser Circulating-Water Pump.—If an attached condenser circulating-water pump is installed it must be given a routine examination to insure that it supplies adequate cooling water.

Piston and Rod Packing.—The compressor pistons are usually packed with cast-iron rings but sometimes with cup leathers. The piston packing should be examined at regular intervals and normally should not require renewal more frequently than once every six months. Where cup leathers are



COMPRESSOR CYLINDER.

used and renewed it is advisable, two days after starting up, to stop the machine and tighten up on the piston nut.

The piston-rod packing should be examined in case there is leakage of gas. A slight leakage of oil around the rod should be permitted. The piston-rod packing should be renewed about once a year unless examination shows that it is in good condition.

Shutting Down.—Before shutting down see that there is enough oil in the stuffing box. This is done by operating the oil pump with maximum stroke for a few minutes. To shut down, close the suction valve, then stop the machine and shut off condenser water. If the machine is to be stopped for more than one day, shut discharge valve also and tighten up on the gland nut. When the machine is to be stopped for a week or more the piston rod should be kept well covered with oil.

Testing Gages.—Whenever the complete system is shut down the pressure should equalize throughout the system, and all gages should show the same pressure, so that if the gages for the same machine show a different pressure at least one of them is incorrect.

Pumping up Air Pressure for Test.—If it should be necessary to test the system when it is empty, this may be done by closing the suction valve and breaking the joint between the suction valve and the compressor, opening all other valves, and running the machine to pump the system full of oil under the desired test pressure. In doing this great care should be exercised not to allow the compressor to overheat, because a disastrous explosion might occur if the temperature in the pipes should reach the flash point of the lubricating oil.

To Examine the Compressor.—To examine the compressor, close the suction and discharge stop valves, and slack off a joint to let the gas escape. Make sure that all pressure is off the compressor cylinder before opening up. Also in removing the compressor-suction or discharge valves be sure to allow the pressure to leak out before completely removing the valve bonnet.

AMMONIA MACHINES.

OPERATION.

Principle.—The principle of this machine is the same as in the CO_2 machine. The refrigerant is ammonia anhydride, a colorless, irrespirable gas, with an easily recognizable odor. It is slightly combustible when mixed with a sufficient proportion of air, and when mixed with twice its volume of air is capable of being exploded with great violence. It attacks copper and its alloys, so that none of these can be used in the construction of parts of the machine that come in contact with ammonia. Ammonia liquifies at a pressure of 128 pounds per square inch at a temperature of 60 degrees F. and the liquid boils at a temperature of 4 degrees F. at atmospheric pressure.

In this machine the gas is drawn from the system into the compressor cylinder and compressed to about 180 pounds per square inch. The work of compressing heats the gas, which is then discharged through the oil interceptor to the condenser, where the circulating water cools the gas and condenses it to a liquid. From the condenser the liquid passes to the liquid receiver, then through the main liquid valve to the regulating (expansion) valve, and then to the cooling coils in direct-expansion systems and to the evaporator in brine systems. From the cooling coils or evaporator the gas returns to the compressor at a pressure between 15 and 30 pounds, completing the cycle of operations.

Cleaning the System.—Before starting a new plant great care should be exercised to thoroughly clean all parts of the system, as the ammonia will loosen all scale and dirt remaining in the system and this foreign matter is sure to cause much trouble.

Testing the System.—Before charging a new plant with ammonia, or after overhauling an old one, test it to 300 pounds per square inch with air. To do this the stop valve is closed on the suction line, and the valves provided on the suction side of the compressor to connect it with the atmosphere, are

opened. In case there are no valves provided, a flange joint between the stop valve and the compressor may be broken and held apart with wedges. All other valves of the system, excepting those which communicate with the atmosphere, as drains of oil tank, etc., should be open so that the pressure will be removed and equalized over the entire system. The compressor heads are removed, and a very small quantity of cylinder oil rubbed on the inside of the cylinder to prevent heating, but if too much oil is used it may be the cause of an explosion. The heads are then replaced and the bolts set up evenly and tight. By running the machine slowly, air is drawn in and compressed until the entire system of pipes, etc., is under pressure of 300 pounds per square inch. Care should be taken to see that stop valve on the discharge pipe is open, for, otherwise, excessive pressure will be had in the compressor at starting and a dangerous accident, such as the blowing out of a cylinder head, may be the result of the oversight. In pumping up the air pressure, the machine should be immediately stopped if the discharge pipe or compressor become excessively hot.

Having obtained the desired test pressure in the system, the machine is shut down and the stop valve on the discharge line is closed; soap lather is spread over all the pipes, flanges, valves and connections; and a very close and systematic inspection of the system from the compressor to the last joint of the pipe line is carefully made.

Leaks.—Leaks at joints should be remedied by tightening the bolts or by new gaskets. All leaks are detected by the appearance of bubbles in the soap lather; those on the pipes may be round holes, or may be in the direction of the pipe length. It is good practice to renew any section of pipe that shows any signs of leaks, but if it is not possible to renew, the leaks may be repaired by using solder and a short clamp. A small round hole is repaired by filling it with solder. Some of the holes are very small and can be detected only with the aid of a magnifying glass. Every care should be taken to de-

tect and stop them, as otherwise more or less loss of ammonia will be incurred when the system is charged.

After all the repair work is done the plant should be allowed to stand for several hours, at the end of which time the pressure will be same as at first; providing everything is tight. In any case the gage should not fall more than 20 pounds.

Before letting the air out it is best to blow through all valves and pipes to make sure that they are clear and to thoroughly free the system from all dirt and moisture. The air then is let out by opening the valves at the lowest point, or points, on the system, such as at the bottom of the oil-separator reservoir, and expansion coils.

Charging.—It is next necessary to pump the air out of the system and to get as near a perfect vacuum as possible. This is done by closing the compressor-discharge stop valve and all the valves that communicate with the atmosphere. Communication with the atmosphere is then made between the stop valve just closed and the compressor. There is usually a valve provided for this purpose. Next open all suction and discharge valves in the system except the one just mentioned, and start the compressor slowly. By running the compressor the air in the system is pumped out until the gage shows 30 inches. If a vacuum of 30 inches can not be obtained, at least a 28-inch vacuum should be obtained before stopping the compressor. This being done, close the discharge valve to the atmosphere and the machine is ready for charging.

Liquid anhydrous ammonia is shipped in cylindrical steel drums. They vary in size, ranging from 50 pounds to 110 pounds. The shell is about ¼ inch thick. A valve is provided at the end for connecting the charging pipe, and a false head over the end of the drum protects the valve during shipment. These drums should be handled with great care and should never be jarred nor exposed to the heat of the sun. Anhydrous ammonia acts in some cases as an explosive and expands when the flask is moved suddenly. When the flasks are stored they

should be kept in a cool place. A connection for charging is provided on or near the liquid-ammonia receiver near the expansion valves, and the flask should be connected to this by a ⅜-inch pipe, the other end should be elevated about 12 inches. The valves on the flask should be opened very carefully at first to see that the connections are tight, and then closed.

If the connections are found to be tight, turn on the circulating water, have a pail of water standing by in case of leaks. If a double-acting compressor, pump oil in the stuffing box of the compressor; if a single-acting compressor, see that the gage glass on the compressor-crank case is half full of ice-machine oil; open the stop valves on the compressor discharge and suction; close the main liquid valve which is between the charging valve and the liquid receiver; start the machine running slowly; open the charging valve and gradually open the valve on the flask. It is best to charge the system by degrees. At the first charging about 70 per cent. of the whole amount to be used is put into the system and thoroughly circulated, after which the air will be found in the top of the condenser, or at the high point of the system where it can be allowed to escape to atmosphere through the purging valve. Rather than allow the air to escape to the atmosphere it is better to connect one end of a flexible-rubber hose to the purge cock, the other end being led into a bucket of water. When the purge cock is open the air will come away and will be seen in bubbles in the water, and there will be no smell as long as air is coming. When all the air has been driven out and ammonia commences to pass, the bubbles will disappear, the smell of ammonia will be noticed, and the purge cock should be immediately closed. The remaining ammonia is charged in one or two installments, the air being allowed to escape in the same manner before each successive charging. To get all of the ammonia out of the drum, it is advisable to heat the drum with hot water, or a blow torch if carefully used. In this way the frost formed on the inside of the drum is removed and the ammonia is allowed to run out. In disconnecting the drum close the charg-

ing valve first and then close the valve on the flask. It is usual to charge the system with 1-3 pound of ammonia for each running foot of 2-inch pipe, or its equivalent in expansion coils. Certain installations of the Brunswick one-ton machines require 50 pounds of ammonia to fill the system and, as a rule, when the machine is installed the makers will have supplied this information. In charging it is better to charge too little than too much, because the additional amount may be added at any time.

Detecting Leaks After Charging.—Ammonia leaks may be easily detected by the use of soapy water or by the use of red litmus paper, as follows:

(*a*) Leaks in the condenser: immerse the litmus paper in the circulating-water discharge, and the presence of ammonia, no matter how little, will be indicated by the paper turning blue.

(*b*) Leaks in submerged coil of (evaporator) ice-making or brine box: immerse the litmus paper in the brine, and if ammonia is present the litmus paper will turn blue.

(*c*) Leaks in the expansion coil or system: dampen the litmus paper and run it along the coil or pipe and upon coming in contact with the leak the paper will turn blue.

A more delicate test of the brine and the circulating-discharge water may be made by the use of Nessler's reagent. This "consists of 17 grms. of mercuric chloride dissolved in about 300 cc. of distilled water, to which is added 35 grms. of potassium iodide dissolved in 100 cc. of distilled water, and constantly stirred until a slight permanent red precipitate is produced. To the solution thus formed is added 120 grms. of potassium hydrate dissolved in about 200 cc. of distilled water, allowed to cool before mixing; the amount is then made up to 1 liter, and mercuric chloride added until a permanent precipitate again forms. After standing for a sufficient time, the clear solution can be placed in glass-stoppered blue bottles and kept in a dark place. If a few drops of this reagent be added to a sample of the suspected brine or water in a test tube, or

other small vessel, and the slightest trace of ammonia is present, a yellow coloration of the liquid will take place; a large quantity of ammonia will produce a dark brown." A very convenient and sure method of testing for leaks in exposed piping and joints is by the use of sulphur sticks. Melt in a metal receptacle ordinary sulphur or brimstone, being careful not to burn it, then dip and re-dip thin strips of wood or cardboard in the sulphur until a coating about 1-16 inch thick is formed on them. Light one end of a sulphur stick made as above and pass it along the part of the system to be tested. Any leak of ammonia will be shown by the appearance of dense white smoke about the burning sulphur.

Starting.—As a rule, every particular type of machine operating on this principle has certain distinctive features, but the following instructions will generally be applicable to any type of machine. See Figure 2. To start the machine see that the gage glass on the compressor-crank case is half full of oil; see ring oiler on outboard bearing is supplied with oil; open circulating-water supply valve No. 1 to condenser; see circulating-water supply to compressor jacket, open. See that suction valve No. 3 is closed, open wide discharge by-pass valve A, jack machine until at compression point; start the machine, then be sure to open discharge valve No. 2, next close by-pass valve A, and open suction valve No. 3 one-quarter turn. Run machine slowly until suction gage shows 10 pounds pressure, then gradually open wide suction valve No. 3. Open liquid valve No. 4 and regulate the regulating (expansion) valves. After the machine is started as above, note carefully the temperature of the compressor-discharge pipe. This pipe should be *slightly warm,* if it becomes hot it is a sign that the liquid ammonia is not passing through the regulating valve as rapidly as it should. If at the same time the frost either wholly or partially disappears from the suction valve it is a sign that the regulating valve should be opened a little more. If the discharge pipe becomes cooler than it should be the regulating valve should be closed a little. In adjusting the regulating valve it should

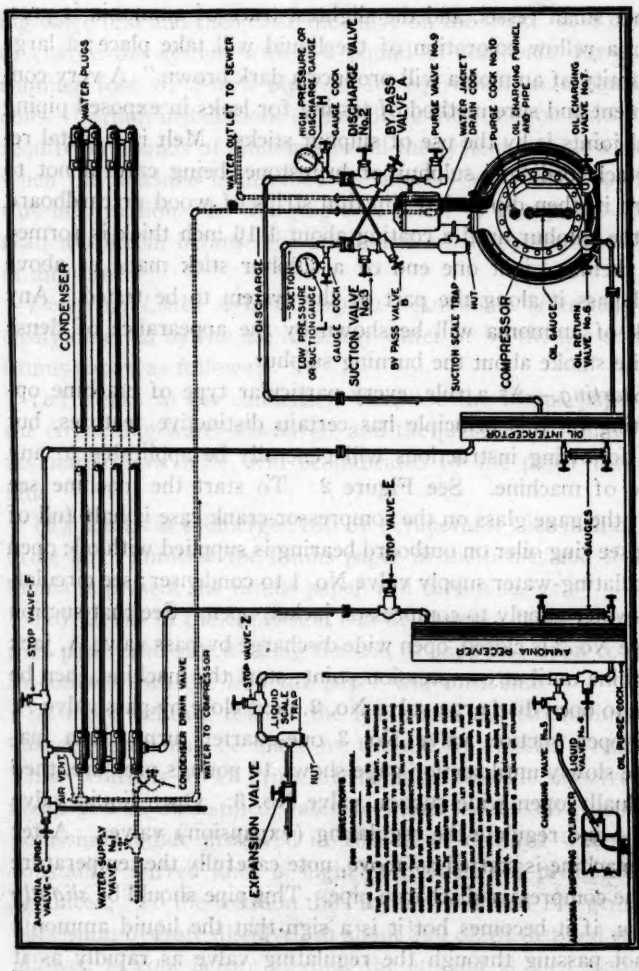


FIG. 2.

be remembered that a very small change in the opening of this valve has a comparatively large effect on the amount of liquid passing through it and that the effect of a slight adjustment of this valve is not apparent for several minutes. Do not change the regulating valves unnecessarily as too much ad-

justing of these valves causes the packing to wear out and leak.

Pressure.—The pressure gages are marked in pressures and the corresponding temperature on two concentric circles. The pressure that should be carried on the condenser depends upon the temperature of the circulating water available because the ammonia pressure depends upon its temperature. The condenser pressure should be carried at the pressure corresponding to a temperature about 10 degrees above the temperature of the discharge-circulating water. The pressure corresponding to a given temperature can be found from the following table:

Properties of Saturated Ammonia Gas.

Temperature, Fahrenheit.	Pressure, pounds per square inch.	Latent heat of evaporation.	Weight of vapor, pounds per cubic foot.
100	200.42	492.01	.7153
90	167.92	498.55	.6120
80	139.40	505.05	.5205
70	114.49	511.52	.4401
60	92.89	517.93	.3697
50	74.26	524.30	.3084
40	58.29	530.63	.2554
30	44.72	536.91	.2099
20	33.25	543.15	.1711
10	23.64	549.35	.1383
0	15.67	555.50	.1107
—10	9.10	561.61	.0878
—20	3.75	567.67	.0690
—30	—0.57	573.69	.0535
—40	—4.01	597.67	.0410

For example, if the temperature of the discharge-circulating sea water is 80 degrees F. the condenser pressure should be that which corresponds to 90 degrees F. or about 168 pounds.

The evaporator or suction pressure should be that corresponding to a temperature 10 degrees F. below that of the brine in the brine tank, where the expansion coils are immersed in brine, and to a temperature 20 degrees F. below that of the air if the expansion coils are cooling air direct. For

example, if the temperature of the brine is 10 degrees F. the suction pressure should be that corresponding to 0 degree F. or 15.67 pounds per square inch, or if the temperature of the air in rooms cooled by direct expansion coils is 20 degrees F. the suction or evaporator pressure should be about 15 pounds per square inch.

If the pressure given above, making allowances for differences in temperatures of circulating water and brine, are maintained and the hands of the pressure gages pulsate at every stroke of the piston, it is probable that the machine is working properly.

Circulating Water.—On board ship where the circulating water can be supplied at no cost except the small amount of power used it is best to use the full capacity of the system, because the lower the temperature of the discharge-circulating water the lower the condenser pressure that can be carried and the less the work required of the compressor.

Faulty Operation.—If the machine is not working properly it may be due to one of the following causes:

1. Shortage of gas in the system;
2. Air in the system;
3. Oil in the system;
4. Leaking valves;
5. Defective packing.

Insufficient Gas in the System.—If the regulating valve cannot be adjusted so as to keep the compressor-suction pipe frosted and the discharge pipe warm the trouble is probably due to insufficient gas in the system. The fact that the system is short of ammonia may be known for certain by placing the ear near the regulating valve; if gas is passing through the valve a distinct whistling sound will be heard, but if there is no shortage of ammonia only liquid will be passing through the valve and the sound will be a hissing one easily recognized by the operator. If there is insufficient ammonia add more to the system until the gage glass on the liquid receiver shows

sufficient liquid or until the frost on the compressor suction pipe appears. Be careful not to overcharge the system.

Air in the System.—If there is air in the system, it displaces a certain amount of gas that should be in use, and the indications of the presence of air are much the same as those of a shortage of ammonia except that the passage of the liquid through the regulating valve will be interrupted by air bubbles which will give an intermittent whistling sound. The remedy is to remove the air, as previously described, and add more liquid ammonia if needed.

Oil in the System.—The presence of any considerable amount of oil or water in the system will cause a reduction in efficiency and will be indicated by shocks within the compressor cylinder. The oil should be removed through the drain valve on the oil interruptor.

Leaking Compressor Valves.—If either valves or piston are suspected of leaking, the fact may be determined with a fair degree of certainty by closing the regulating valve, and continuing the machine in operation. The evaporator (suction) pressure should be pumped down to about 20 per cent. of what it was in a certain number of revolutions, which should be stated by the manufacturer of the particular machine or determined on board ship when the machine is known to be in good condition. If the valves are leaking it should be possible to detect this by listening carefully with the ear near the compressor cylinder. Irregular and faulty action of the valve should be indicated by the irregular pulsation of the pressure gages. If the valves are leaking badly it will be impossible to pump down the suction pressure in order to remove the valves so that the gas should be expelled from the cylinder as follows: Close the regulating valves tight, then close the compressor-suction stop valve, stop the machine, turn the machine to top center, close the discharge stop valve, then turn the machine one complete revolution; open the discharge stop valve to let the pressure blow into the condenser. Repeat this operation several times, then open the cylinder, having water

and a large wet sponge at hand to absorb the ammonia remaining in the cylinder.

Defective Packing.—If the compressor valves are in good condition, sufficient gas in the system, no other faults located, but the machine shows decreased capacity, the piston packing is probably worn and should be examined.

Shutting Down.—To stop the machine close the expansion valve or, better, the liquid valve between the expansion valve and the liquid receiver; pump the low-pressure side of the system down to a pressure of 2 pounds. Do not pump down to a vacuum. Close the suction stop valve, stop the machine, close the discharge stop valve and shut off the circulating water.

Adjusting Lift of Valves.—Special attention should be given to the lift of the compressor valves, for if the lift is too high the valves will not close promptly, and the machine will be inefficient, especially if the machine is run at high speed.

Removing Oil from System.—The system should be completely freed from oil when opportunity offers, as it clogs up the pipes, reduces the efficiency of the machine and the conductivity of the piping. To remove the oil, stop brine pump, slow down the circulating pump, let the hot ammonia circulate through the system, open expansion valve equalizing the pressure on the high and low sides. The oil is carried through the system back to the oil interruptor or trap, and this trap should be blown down every fifteen minutes until the system is free of oil. After the system is free of oil the machine may be started up or shut down in the usual way, increasing the supply of circulating water and closing the regular valve.

A LENGTH COMPARATOR, FOR DETERMINING LINEAR COEFFICIENTS OF EXPANSION.

WM. L. DEBAUFRE, MECHANICAL ENGINEER.

In the conduct of the varied experimental and research work required of the U. S. Naval Engineering Experiment Station it is often necessary to design and build special apparatus. Whenever deemed advisable such apparatus is designed along broad lines to serve for other purposes in addition to those for which it is especially desired. Thus, when the problem was presented of measuring the coefficients of expansion of lead-tin alloys, it was deemed advisable to make a length comparator which would be available for conveniently calibrating scales and comparing lengths in general, as well as for determining within one per cent. the coefficients of expansion of the alloy bars mentioned. The construction and operation of this comparator will be described together with the method of calculating the coefficients of expansion.

CONSTRUCTION.

As shown in the sectional elevations in Fig. 1 and Fig. 2 and in the photograph, Fig. 3, the essential parts of the comparator are the carriage C supporting the two micrometer microscopes M, and the two troughs T containing supports for a standard scale and the test bar respectively. These supports consist of a series of rollers, see Fig. 1, all lying in the same plane and aiding in the support of the bar or scale, which in this way is free to expand without buckling.

Each trough T is filled with oil, which can be circulated through it and the pipe P below by means of the motor-driven propeller at the right-hand end. Resistance wire is wound around pipe P to form a heating coil, the electric current

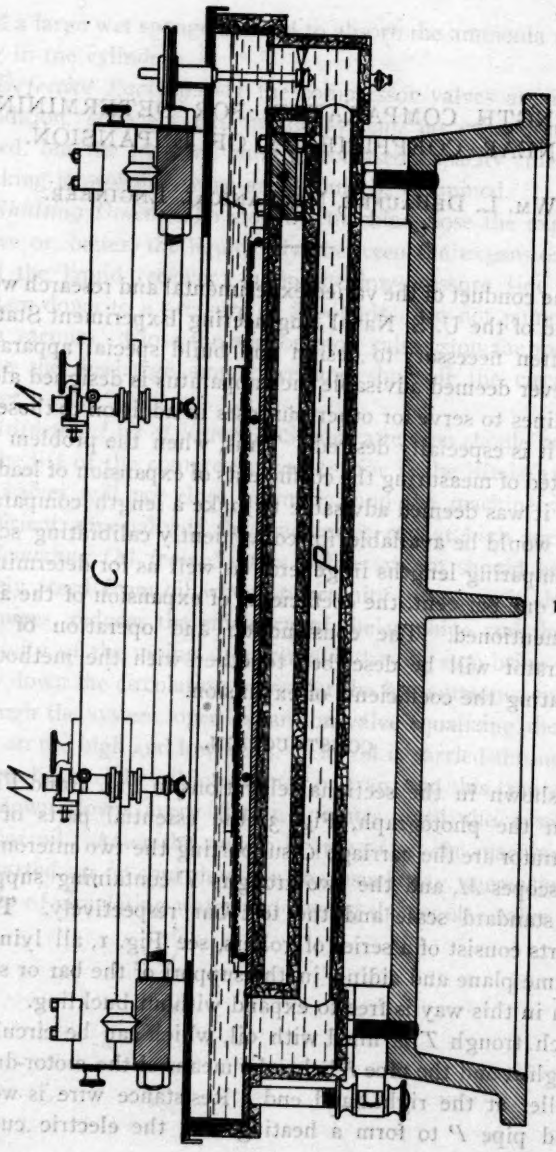


FIG. 1.

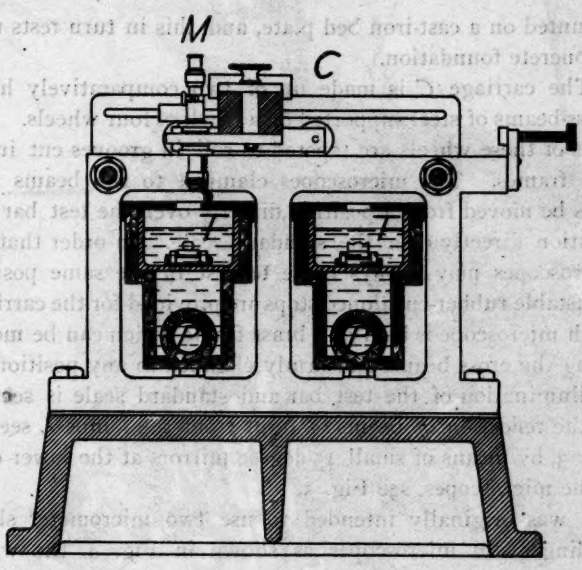


FIG. 2.

through which is regulated by the rheostats *R* seen in Fig. 3. The two troughs are in no way connected together, so that the temperature of each may be regulated independently of the other. To reduce radiation of heat from the oil baths the pipes and the sides and bottoms of the troughs are covered with magnesia, and removable top covers of sheet iron lined with asbestos are provided. It is planned to apply some form of electric heating pads to the sides and bottoms of the troughs to maintain a perfectly uniform temperature throughout. The oil may be removed from the troughs through the pet cocks shown.

Each trough is supported in the end frames upon a horizontal bar at the right-hand end and a vertical rod at the left-hand end. The former is turned off center to act as an eccentric and thus raise or lower the right-hand end of the trough by rotating the bar. The vertical rod at the left-hand end is threaded to serve the same purpose. The two end frames are

mounted on a cast-iron bed plate, and this in turn rests upon a concrete foundation.

The carriage *C* is made up of two comparatively heavy cross-beams of steel supported on a truck of four wheels. The rims of these wheels are tapered to roll in grooves cut in the end frames. The microscopes clamped to the beams may thus be moved from a position directly over the test bar to a position directly over the standard scale. In order that the microscopes may always come to rest in the same position adjustable rubber-cushioned stops are provided for the carriage. Each microscope is held in a brass frame which can be moved along the cross beams and firmly clamped in any position.

Illumination of the test bar and standard scale is secured by the reflection of beams of light from the lamps *L* seen in Fig. 3, by means of small 45-degree mirrors at the lower ends of the microscopes, see Fig. 5.

It was originally intended to use two micrometer slides holding plain microscopes as shown in Fig. 4, the whole microscope being moved bodily by means of a screw having a pitch of 0.5 millimeter. As the circumference of the micrometer head *H* at the end of the slide is divided into 100 equal parts, one division corresponds to a difference in reading of 0.005 millimeter or about 0.0002 inch on the test bar or scale. However, it was found impossible to duplicate readings within 2 divisions or 0.0004 inch. The cross-hairs in these microscopes intersect at an angle of 60 degrees, and the readings are taken when the image of the mark sighted on bisects the angle between the cross-hairs.

It was therefore decided to substitute micrometer microscopes as seen in Fig. 5. When looking through the eye piece of a micrometer microscope there is visible in the focal plane, Fig. 7, two parallel cross-hairs, a series of teeth, and the images of the marks on the scale sighted upon. The parallel cross-hairs are movable by means of the divided micrometer head seen in Fig. 5, one tooth corresponding to one turn. With 100 divisions on the head and a screw having a pitch of 0.25 millimeters, one division corresponds

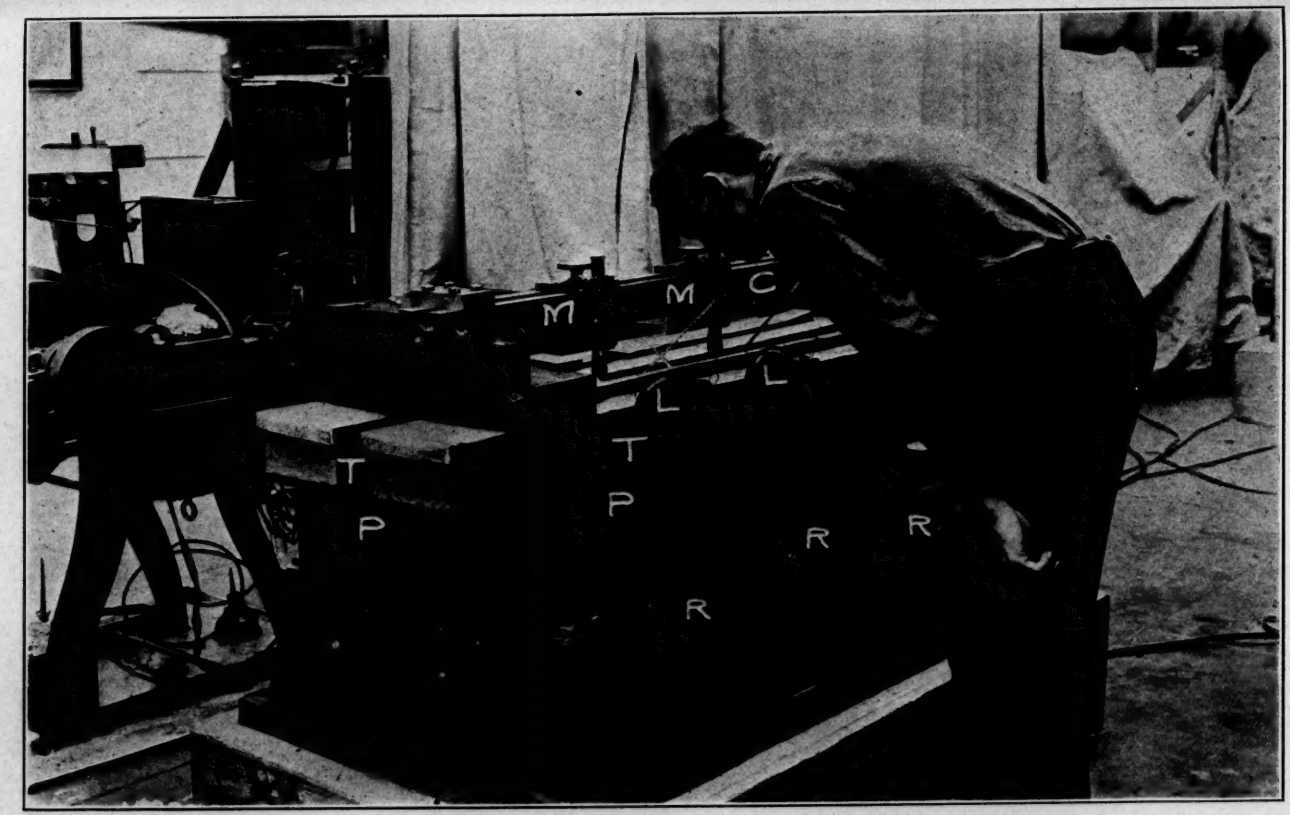


FIG. 3.

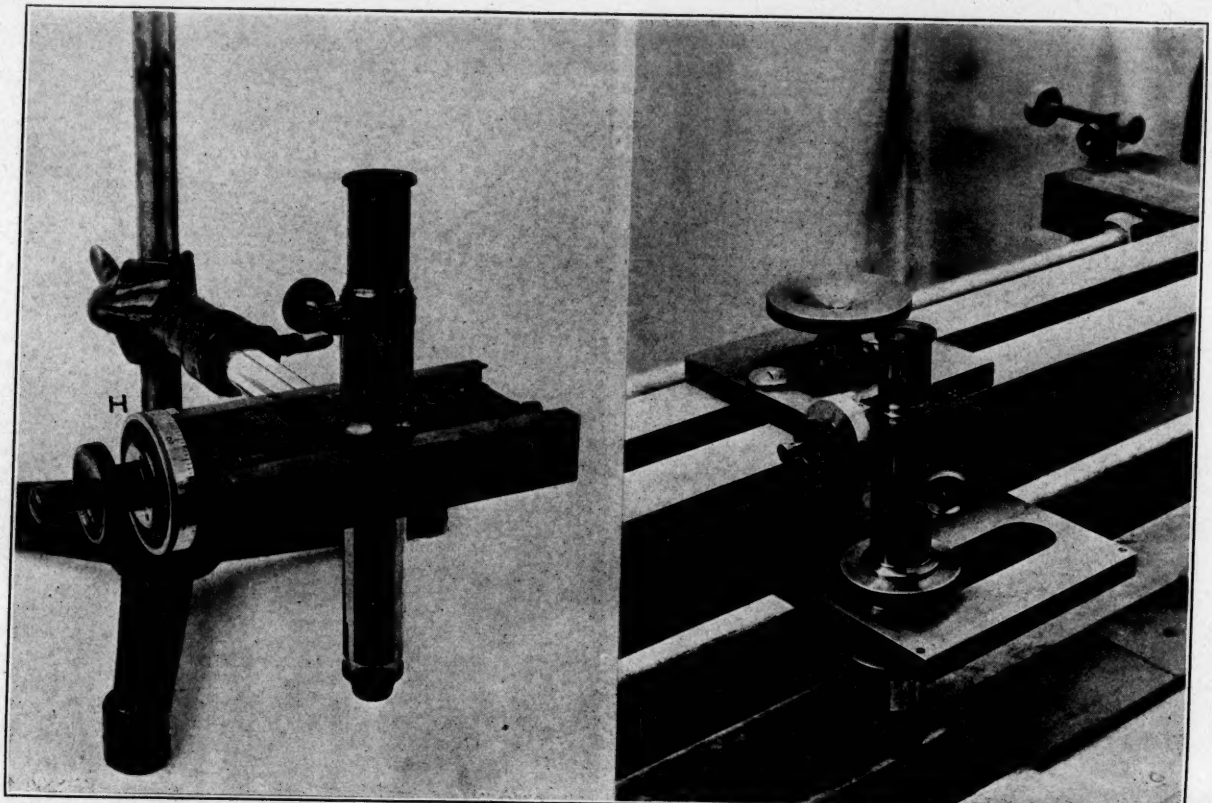


FIG. 4.

FIG. 5.

to a movement of the cross-hairs of 0.0025 millimeters or about 0.0001 inch. These cross-hairs move across the magnified image of the scale; and as the magnification of the objectives in the microscopes used in this comparator was about 2.5, one division on the screw head actually corresponds to a difference in reading of about 0.001 millimeter or 0.00004 inch on the test bar or standard scale. It was found possible by very careful manipulation to duplicate readings to within 2 divisions corresponding to 0.00008 inch. When a reading is taken, the parallel cross-hairs should be on either side and equally distant from the image of the mark sighted upon.

As ordinarily furnished by the manufacturer, the micrometer microscopes have objectives giving a magnification of 3.5, but the lower end of the microscope must then be within about 2

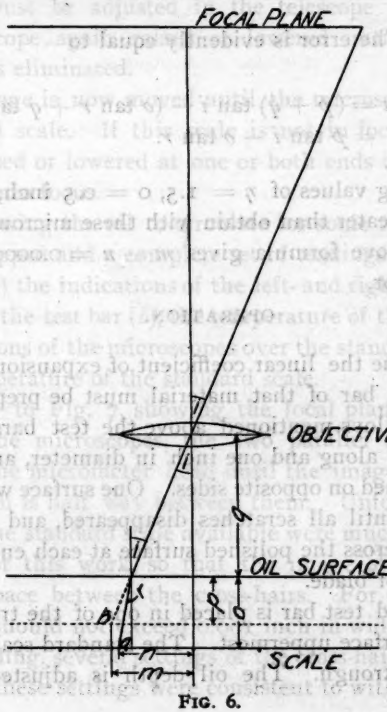


FIG. 6.

FIG. 5.

FIG. 4.

inches of the object. For this comparator it was required that the objective be 3 inches above the object to bring the lower end of the microscope above the top of the trough. Special objectives were therefore fitted having a focal length of 2 inches, and a corresponding magnification of about 2.5 in this microscope.

In using the micrometer microscope to measure distances upon a scale immersed in oil the question arose as to the possibility of an error due to the refraction of light waves by the oil. By referring to Fig. 6 it may be proven that the error introduced thereby is negligible. Thus, the mark which is actually on the scale at a appears to be located at b due to the velocity of light through oil being less than through air. Denoting the index of refraction by η, we have $\eta = \frac{o}{p}$ and also $\eta = \frac{\sin i}{\sin r}$. The error is evidently equal to

$$\begin{aligned} m - n &= (p + q) \tan i - (o \tan r + q \tan i) \\ &= p \tan i - o \tan r. \end{aligned}$$

By assuming values of $\eta = 1.5$, $o = 0.5$ inch, and $i = 2$ degrees, all greater than obtain with these micrometer microscopes, the above formula gives $m - n = 0.000004$ inch, a negligible error.

OPERATION.

To determine the linear coefficient of expansion of a given material a test bar of that material must be prepared. For the lead-tin alloys mentioned above the test bars were cast about one foot along and one inch in diameter, and two surfaces were planed on opposite sides. One surface was polished at each end until all scratches disappeared, and a very fine line was cut across the polished surface at each end by means of a sharp razor blade.

The prepared test bar is placed in one of the troughs with the marked surface uppermost. The standard scale is placed in the other trough. The oil depth is adjusted to equal

amounts over the standard scale and test bar, both of which should be very closely horizontal.

The microscopes are then moved along the carriage and clamped over the marks on the test bar upon which they are focused. The latter is accomplished by moving the microscope bodily up or down until the images of the marks are distinct when viewed through the eye pieces. The eye pieces should first have been adjusted to bring the cross-hairs therein into focus. However, it may be found by moving the eye back and forth over the eye piece, that an an apparent movement of the cross-hairs occurs relative to the image of the mark sighted upon. If so, the image of the cross-hairs is not in the plane of the image of the mark on the test bar. To avoid the error that may thus result, due to "parallax," the eye piece must be adjusted in the telescope tube and the whole telescope again raised or lowered until all relative movement is eliminated.

The carriage is now moved until the microscopes are over the standard scale. If this scale is not in focus the trough must be raised or lowered at one or both ends until the scale is brought into focus.

After allowing the oil to circulate for some time the circulation is stopped and a complete set of readings is taken, consisting of (*a*) the indications of the left- and right-hand microscopes over the test bar (*b*), the temperature of the test bar (*c*), the indications of the microscopes over the standard scale, and (*d*) the temperature of the standard scale.

Referring to Fig. 7, showing the focal planes of the eye pieces of the microscopes, the two parallel cross-hairs are moved by the micrometer head until the image of the mark sighted upon is half way between them. Unfortunately, the marks on the standard scale available were much coarser than desirable for this work, so that the image of one of them filled the space between the cross-hairs. For accurate work the marks should not exceed 0.001 inch in width. However, at each reading, several settings of the cross-hairs were always made, and these settings were consistent to within 2 divisions

on the micrometer head, the average being recorded for the reading which can thus probably be considered accurate to less than one division or 0.00004 inch. Also, the cross-hairs were set by always turning the micrometer head in the same direction, thus eliminating errors due to lost motion. The reading was recorded as the number of turns (teeth) and fractions of a turn (micrometer-head divisions) from the extreme left-hand position of the cross-hairs in the focal plane.

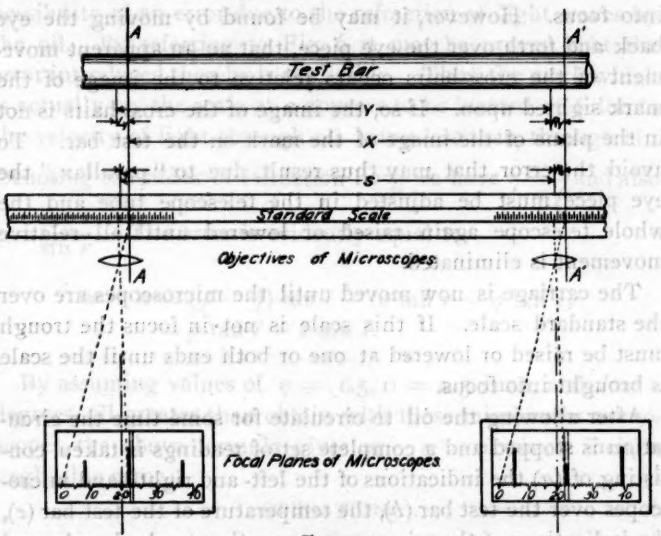


FIG. 7.

In the case of the 12-inch alloy bars the temperatures were read on three mercury-in-glass thermometers placed at each end and near the center of the bar, and at different depths in the oil. The heating of the oil in the pipe beneath the trough was found to produce strata of oil of different temperatures, but readings were not taken until these strata disappeared, as indicated by the substantial equality of the indications on the three thermometers. The oil bath for the standard scale was not heated, and its temperature was taken by a single thermometer laid on the top of the portion of the scale between the graduations sighted on.

For each temperature of the test bar three complete sets of the readings (*a*), (*b*), (*c*) and (*d*) were taken. The several temperatures of the test bar were approximately 70, 100, 125, 150, 175 and 200 degrees F. As the oil over the test bar expanded at the higher temperatures it was found necessary to remove some of it to maintain the same depth and thus keep the marks in focus. It was also found necessary to stop the circulation of the oil before taking readings in order to eliminate the apparent oscillation of the marks sighted on, caused by wave motion at the surface of the oil.

Since the readings are recorded in terms of the number of turns of the screw in moving the cross-hairs from their extreme left-hand position to the position of the image of the mark sighted on, the micrometer microscope must be calibrated. By this is meant the determination of the actual distance on the object which corresponds to the apparent motion of the cross-hairs produced by one turn of the micrometer screw. The desired relation is evidently dependent upon the pitch of the micrometer screw and the magnification of the objective of the microscope. The calibration may readily be made, however, by noting the indications when the cross-hairs correspond to the left- and right-hand marks of a chosen length on the standard scale. Thus, if readings of 30.801 and 6.102 turns were obtained for a length of 0.1 inch, then $\frac{30.801 - 6.102}{0.1} = 246.99$ turns correspond to one inch, and all readings of that micrometer microscope in turns must be divided by 246.99 to obtain the corresponding distance in inches. Of course, several such calibrations should be made, selecting different distances on the standard scale.

METHOD OF CALCULATION.

The method of calculating results from the data obtained as above described can best be explained by referring to Fig. 7. First it should be noted that recording the apparent distance of the cross-hairs from the left-hand ends of the toothed scales in the microscopes refers all measurements to

two imaginary lines across the standard scale and test bar, AA and A′A′ respectively. Let L_s and R_s be the distances from these imaginary lines of the graduations read on the standard scale, and let L_y and R_y be the corresponding distances of the marks on the test bar from these imaginary lines, as indicated on Fig. 7. If the distance between the imaginary lines be denoted by X, we have

$$S - L_s + R_s = X = Y - L_y + R_y,$$

whence

$$Y = S - L_s + R_s + L_y - R_y.$$

The values of L_s and L_y and of R_s and R_y are obtained by dividing the readings of the left- and right-hand micrometer microscopes respectively, by the calibration constants obtained as described in a preceding paragraph. The value of S is obtained from a direct reading of the standard scale, corrected for calibration errors and for any change in length due to the temperature in the comparator being different from the calibration temperature of the standard scale. The latter correction is given by

Temperature correction for standard scale $= \alpha\ L\ (t - t_0)$, where

α = coefficient of expansion of the standard scale;
L = length read on standard scale;
t_0 = temperature of calibration of standard scale; and
t = temperature of standard scale in comparator.

To obtain the coefficient of expansion of the test bar, the lengths obtained by applying the above formula for Y to the several observations, are plotted against the average temperatures of the test bar at the several readings, as shown in Fig. 8 for a certain alloy bar. The linear coefficient of expansion is defined as the change in length per degree Fahrenheit or centigrade per unit of length at the temperature of melting ice. The length at t_1 degrees Fahrenheit is therefore given by

$$L_1 = L_{32} + \alpha\ L_{32}\ (t_1 - 32) = [1 + \alpha\ (t_1 - 32)]\ L_{32}.$$

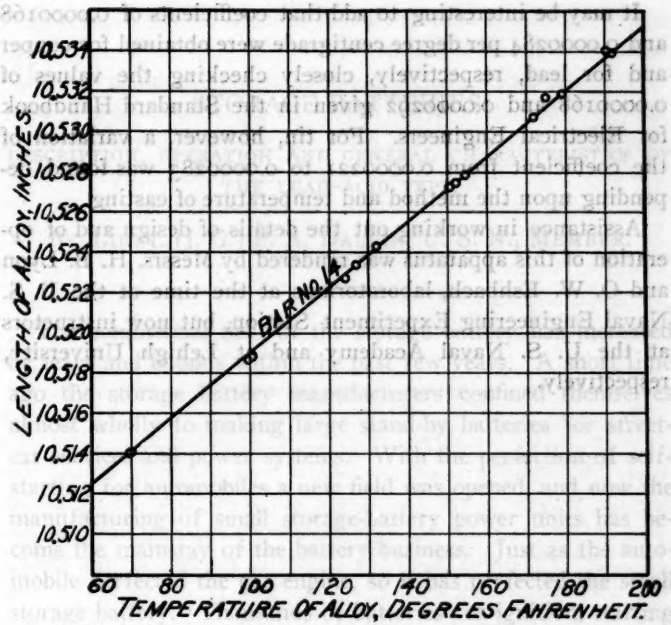


FIG. 8.

For t_2 degrees Fahrenheit, we likewise have

$$L_2 = [1 + \alpha (t_2 - 32)]\, L_{32}.$$

Eliminating L_{32} from these two equations, we obtain

$$\alpha = \frac{L_2 - L_1}{L_1 (t_2 - 32) - L_2 (t_1 - 32)}.$$

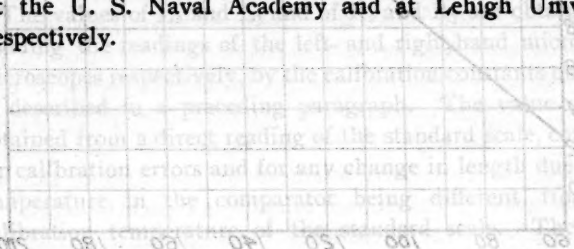
By selecting from the curve in Fig. 8 (drawn to a larger scale), $L_1 = 10.51073$ inches corresponding to $t_1 = 50$ degrees Fahrenheit and $L_2 = 10.53530$ inches corresponding to $t_2 = 200$ degrees Fahrenheit, we obtain

$$\alpha = \frac{10.53530 - 10.51073}{10.51073 \times 168 - 10.53530 \times 18} = 0.0000156$$

per degree Fahrenheit for the case in hand.

It may be interesting to add that coefficients of 0.0000168 and 0.0000284 per degree centigrade were obtained for copper and for lead, respectively, closely checking the values of 0.0000168 and 0.0000292 given in the Standard Handbook for Electrical Engineers. For tin, however, a variation of the coefficient from 0.0000221 to 0.0000283 was found, depending upon the method and temperature of casting.

Assistance in working out the details of design and of operation of this apparatus was rendered by Messrs. H. B. Lyon and O. W. Eshbach, laboratorians at the time at the U. S. Naval Engineering Experiment Station, but now instructors at the U. S. Naval Academy and at Lehigh University, respectively.



STORAGE BATTERIES.

DESCRIPTION, OPERATION AND GENERAL CHARACTERISTICS OF THE LEAD–ACID TYPE.

By Lieut. (J. G.) F. A. Daubin, U. S. N., Member.

The commercial field of the storage battery has increased by leaps and bounds within the past few years. A short time ago the storage battery manufacturers confined themselves almost wholly to making large stand-by batteries for street-car services and power systems. With the perfection of self-starting for automobiles a new field was opened, and now the manufacturing of small storage-battery power units has become the mainstay of the battery business. Just as the automobile perfected the gas engine, so it has perfected the small storage battery. Thousands of batteries for ignition, starting and lighting of automobiles are turned out annually. The uses to which batteries are being put do not confine themselves to automobiles, however. Their power is required for electric automobiles and trucks, Pullman lighting and power, farm and building lighting, and many other purposes. In the Navy storage batteries formerly were rarely found outside submarines or motor boats, but today every battleship has on board from forty to sixty cells, and the new battleships will find use for four or five hundred cells. It is the purpose of this article to deal only with the small storage battery used or to be used on battleships.

A storage battery does not store electrical energy as a condenser, or power as a reservoir; a storage battery stores chemical energy. During the process of charging electrical energy is transformed into chemical energy and stored within the cell, while during the process of discharging chemical energy is transformed into electrical energy. The transformations are

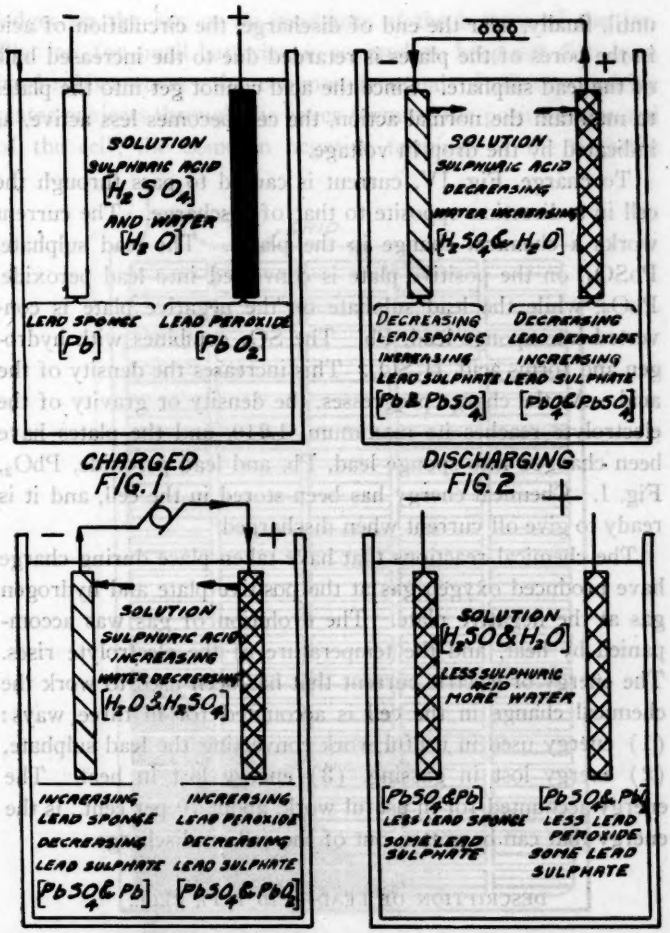
made with a loss which prevents as much energy being drawn from the cell as was put into it.

There are two general types of storage battery, the lead-acid type and the alkaline type. In the former cell the positive plate is composed of lead peroxide, PbO_2, the negative plate of pure spongy lead, Pb, and the electrolyte is sulphuric acid, H_2SO_4, and water, H_2O. In the alkaline type of storage battery the active material of the positive plate is nickel hydrate, the active material of the negative plate is iron oxide, the electrolyte is potassium hydrate. This article will be confined to the discussion of the lead-acid type of cell.

CHEMICAL ACTION DURING CHARGE AND DISCHARGE.

When a cell is charged, Fig. I, the negative plate is sponge lead, Pb, and the positive plate is lead peroxide, PbO_2, the specific gravity of the electrolyte, sulphuric acid, H_2SO_4, and water, H_2O, will be the maximum 1.210, temperature 80 degress F. Chemical energy is stored in the cell in this condition. If the cell is put on discharge, Fig. II, the H_2SO_4 of the acid is divided into H_2 and SO_4. The H_2 passes in the direction of the current to the positive plate, and combines with the oxygen of the lead peroxide and forms H_2O, this converts the positive plate into lead oxide, PbO. The lead oxide, PbO, combines immediately with the H_2SO_4 and forms lead sulphate, $PbSO_4$, and water, H_2O. The sulphion, SO_4, also forms lead sulphate at the negative or sponge lead, Pb, plate. As the discharge progresses both plates are finally reduced so that they contain considerable lead sulphate, $PbSO_4$, Fig. III. The water formed has diluted the acid until the specific gravity of the electrolyte is lowered. When the plates are entirely sulphated current will cease, since the plates are identical, and any electric cell requires two dissimilar plates in electrolyte. In common practice, however, the discharge is always stopped before the plates have become entirely reduced to lead sulphate.

The lead sulphate that has been formed by the acid in contact with the plates is more bulky than the sponge lead or



CHARGED FIG. 1

DISCHARGING FIG. 2

CHARGING FIG. 4

DISCHARGED FIG. 3

E.S.B.CO.

lead peroxide. It is often noticed that copper sulphate on copper, or iron rust on iron, is more bulky than the amount of copper or iron eaten away. The lead sulphate, on account of its increased volume, fills the pores of the active material

until, finally, near the end of discharge, the circulation of acid in the pores of the plates is retarded due to the increased bulk of the lead sulphate. Since the acid cannot get into the plates to maintain the normal action, the cell becomes less active, as indicated by the drop in voltage.

To charge, Fig. IV, current is caused to pass through the cell in a direction opposite to that of discharge. The current works a chemical change in the plates. The lead sulphate, $PbSO_4$, on the positive plate is converted into lead peroxide, PbO_2, while the lead sulphate on the negative plate is converted into sponge lead, Pb. The SO_4 combines with hydrogen and forms acid, H_2SO_4. This increases the density of the acid. As the charge progresses, the density or gravity of the electrolyte reaches its maximum, 1.210, and the plates have been changed into sponge lead, Pb, and lead peroxide, PbO_2, Fig. I. Chemical energy has been stored in the cell, and it is ready to give off current when discharged.

The chemical reactions that have taken place during charge have produced oxygen gas at the positive plate and hydrogen gas at the negative plate. The evolution of gas was accompanied by heat, and the temperature of the electrolyte rises. The energy or electric current that has been used to work the chemical change in the cell is accounted for in three ways: (1) energy used in useful work converting the lead sulphate, (2) energy lost in gassing, (3) energy lost in heat. The energy accounted for in useful work, about 70 per cent., is the energy that can be gotten out of the cell on discharge.

DESCRIPTION OF LEAD–ACID TYPE CELL.

A lead type of battery consists of a number of positive plates and negative plates, insulated from each other by wood veneer, rubber, or wood and rubber separators, immersed in sulphuric acid of suitable density, and contained in a hard-rubber, glass, or earthenware jar. The positive plates are connected in parallel, likewise the negative plates. The plates and separators are supported in the jar by bus bars at the top, by

ledges on the jar, or by insulators at the bottom of the jar. The jar, for small batteries, is covered, to keep out dirt, by a hard-rubber cover; the common terminal of all the positive plates projects through the cover forming the positive terminal of the cell; the common negative terminal of the negative

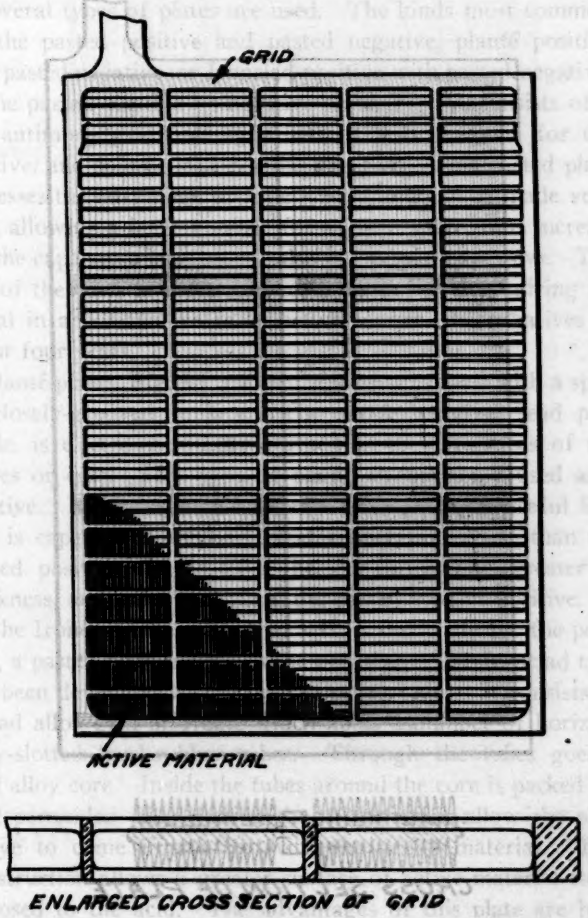
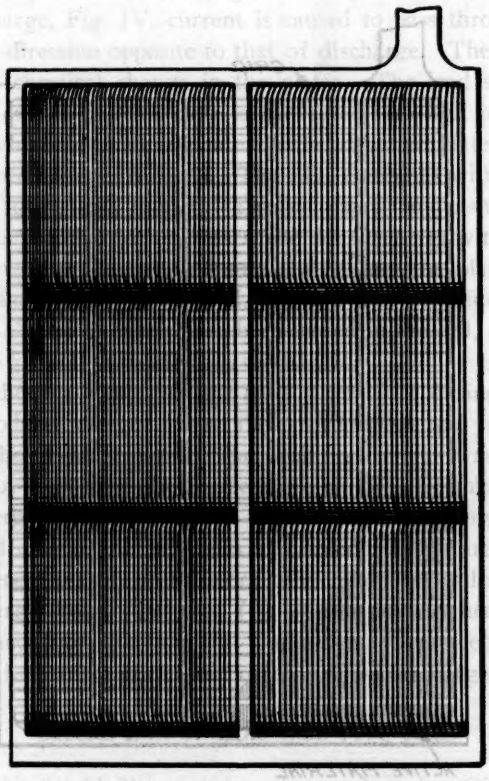


FIG. V PASTED TYPE PLATE

plates projects through and forms the negative terminal of the cell. The cover is sealed on the cell, and has openings in it for adding pure water to the electrolyte, for taking temperature and specific-gravity readings, and for allowing the gas



CROSS SECTION OF PLATE

FIG. VI PLANTE TYPE PLATE

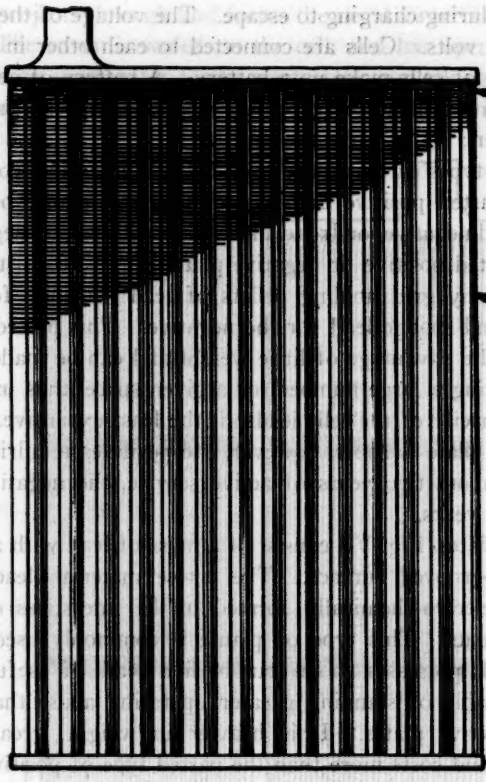
given off during charging to escape. The voltage of the cell is about two volts. Cells are connected to each other in series. A number of cells make up a battery. A battery of cells are placed in a lead-lined or acid-proof wooden box, with or without a cover.

Several types of plates are used. The kinds most common are the pasted positive and pasted negative, planté positive with pasted negative, or Ironclad positive with pasted negative.

The pasted positive or negative plate, Fig. V, consists of a lead-antimony grid holding pellets of lead peroxide for the positive, and sponge lead for the negative. This pasted plate possesses the advantage of little weight and can be made very thin, allowing a large number for a given space, thus increasing the capacity of the cell; it also is the least expensive. The life of the plate is short, however, the positives requiring renewal in about two years of active service, the negatives in about four years.

Planté plates, Fig. VI, consist of a mass of lead with a spun or closely-grooved surface. The active material, lead peroxide, is electro-chemically formed in the interstices of the scores or cuts. This type of planté is commonly used as a positive. It possesses about four or five years of useful life, and is capable of standing greater operating abuse than the pasted positive plates. It is heavier in weight, greater in thickness, and costs more than the pasted type of positive.

The Ironclad-type plate, Fig. VII, is used only for the positive, a pasted plate is used as the negative. The Ironclad type has been developed within the last seven years. It consists of a lead alloy grid or frame which holds a number of horizontally-slotted hard-rubber tubes. Through the tubes goes a lead alloy core. Inside the tubes around the core is packed the lead peroxide. The slots in the rubber tubes allow the electrolye to come in contact with the active material. This construction allows a greater surface of active material to be exposed to the acid. The advantages of this plate are high capacity per square inch of surface, lightness and durability. It is the most expensive of all the types of the lead plates.



CROSS SECTION OF PLATE

FIG. VII IRONCLAD TYPE PLATE

ELECTROLYTE.

The electrolyte as used in all lead batteries consists of a mixture of pure sulphuric acid and water. Concentrated sulphuric acid is a heavy, oily liquid having a specific gravity of

1.835. A battery will not operate if the acid is too strong; it is therefore diluted with pure water to bring it to a gravity of 1.210 for a fully-charged battery.

When the battery is being discharged the gravity becomes weaker, as part of the acid is combined in the plates producing the current. This weakening of the electrolyte will cause the gravity to drop about 70 to 100 points (depending upon the rate of discharge). During charge the acid is driven from the plates and the specific gravity rises.

A hydrometer, indicating the specific gravity of the electrolyte, is therefore used to determine the state of charge or discharge of the battery.

Electrolyte, like most substances, expands when heated, and its specific gravity is affected by a change in temperature. If electrolyte that has a certain specific gravity at 80 degrees F. be heated, the expansion will cause it to have a lower specific gravity of .001 point for every 3 degrees F. rise in temperature. For instance, if the gravity is 1.210 at 80 degrees F. and the temperature is raised to 89 degrees F., the gravity will be 1.207. On the other hand, if the temperature had been lowered from 80 degrees F. to 71 degrees F., the gravity would be 1.213. Change of temperature does not alter the actual strength of the electrolyte, but changes its specific gravity only—one point for every three degrees rise in temperature. For convenience, 80 degrees F. is considered normal temperature, and all gravity readings should be corrected for this temperature for comparison.

AMPÈRE-HOUR CAPACITY.

The ampère-hour capacity of a battery, the cells of which are connected in one series, is the same as that of a single cell in the series. The ampère-hour capacity of a cell depends upon the number of plates of a given type. The ampère-hour capacity of a plate depends upon the amount of available active material it contains. If the plate contains more square inches of active material; *i.e.*, has greater length and width, its ampère capacity will be increased.

The drop in gravity is proportional to the ampère hours out of the battery. For this reason the specific gravity will always give an indication of the state of charge or number of ampère hours in the battery, remembering that the specific gravity varies with the temperature of the electrolyte, and must be corrected to 80 degrees F. The drop in gravity for a battery using 1.210 electrolyte, during a complete discharge, is 70 (.070) points. When the hydrometer reading is 1.140 the battery is ready for a charge.

VOLTAGE.

The average E.M.F. of a lead cell is usually considered as two volts. Although the average voltage on discharge is about 1.85 volts, depending upon the ampère rate of discharge, while the average voltage on charge is about 2.3 volts. The voltage of any particular type of cell depends upon the resistance of the conducting grids of the plates, the resistance of the electrolyte, and the resistance of the active material of the plates. The resistance of the conducting grids will vary with the temperature, that of the electrolyte with the density, and that of the active material with the amount of $PbSO_4$ and with the amount of electrolyte in the plate, and the amount of contact it has with the supporting grid. It is thus seen that size and design of the plate have considerable to do with the voltage of the cell.

CHARGING.

During discharge the lead peroxide and lead sponge are more or less exhausted and partially covered with a layer of lead sulphate. The acid which has worked this chemical change is contained within the plates. It is the function of charging to reduce the layer of sulphate, restoring the plates to lead peroxide and sponge lead, and to release the acid contained within the plates.

When charging, a definite number of ampère hours are needed to reduce the sulphate, the amount depends on the degree of discharge or the degree of normal sulphation. After

a time some of the sulphate has been reduced, and a less number of ampère hours is required for the reduction of the remaining sulphate. The electrical energy not required for this work will be expended in heat, the plates of the battery acting as a rheostat.

An excellent theoretical method of charging would be to start the current at a rate equal to the number of ampères out of the battery, and gradually taper the rate as the sulphate is reduced, keeping the plates just at the gassing point, until all the sulphate has been reduced, when the charging current will have been reduced to 0.

Due to the chemical reactions within the cell, oxygen is liberated at the positive plates and hydrogen at the negative plates, and water is formed. The charging rate being proper, most of the gassing is from the positive plates until near the finish of the charge, when the negative plates begin to gas freely. Very shortly after the charge is stopped, gassing ceases. The phrase "proper charging rate" has been used. If the current is just high enough to reduce the sulphate the plates will just be at the gassing point.

Too high a current will cause excessive gassing. When the plates gas violently the bubbles of gas will carry off or erode particles of active material from the positive plates. It may be taken as a very good rule that when gassing occurs it is time to reduce or stop the charging current.

Fig. VIII shows a typical voltage curve during charging.

The voltage rises quickly at "A" to 2.2 volts per cell. This is due to the resistance offered by the layer of sulphate on the plates, which prevents diffusion of the acid until it has been broken through. As soon as this happens the voltage falls a little at "B." This is an inappreciable amount, and will rarely be discernible on the voltmeter. The voltage rises slowly along that part of the curve marked "C." During this period, the plates are being restored to lead and lead peroxide and acid is being produced. Diffusion, however, is becoming more and more difficult, for the acid must come

from more remote parts of the plates. At "D" the curve rises rapidly and gas is evolved more freely. The voltage continues to rise rapidly through "E," then drops slightly at "F" and runs along parallel to the time axis.

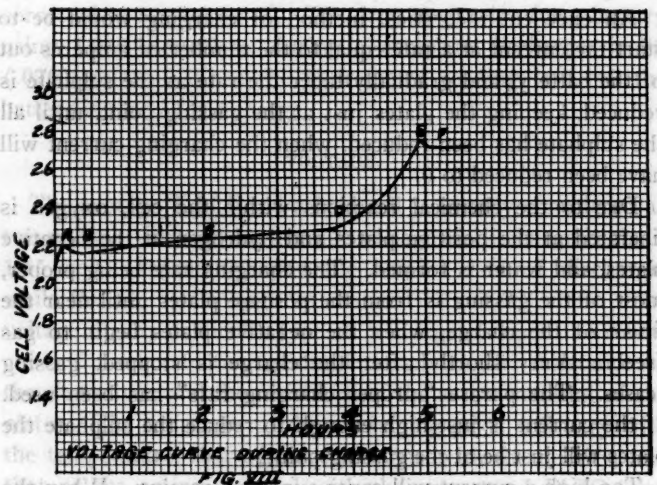


FIG. XIII.

On open circuit the voltage of a fully-charged battery will be about 2.10 volts per cell (for 1.210 acid). This is due to the lead sulphate, some of which is still present even in a charged battery, diffusing out from the interior of the plate.

As the acid is driven from the plates the specific gravity of the electrolyte is increased. This is rather slow at the start of the charge and is not proportional to the ampère hours put in the battery, and there is a distinct lag in the rise of the gravity. As soon as the insulating layer of sulphate is broken the rise in the gravity of the electrolyte becomes proportional to the amount of charge. When all the acid has been driven from the plates and the battery is charged, the specific gravity reaches a maximum. For this reason gravity readings are relied upon to indicate the degree of charge of the battery.

The temperature affects the specific gravity of the acid, a

high temperature causing the gravity to be lower, and a low temperature causing the gravity to be higher. To make the readings useful for comparison they should be corrected to a temperature of 80 degrees F., adding or subtracting one point (.001) to the gravity reading for every 3 degrees the temperature of the battery is above or below 80 degrees F.

During the charge the temperature of the electrolyte must be watched. The maximum temperature allowable is 120 degrees F., with the acid concentration on full charge at 1.210. Excessive temperatures loosen the active material in the plates and evaporate considerable water from the electrolyte, new material is formed in the grids and the plates become weakened. During the charging, if the cells reach the temperature limits the current must be reduced or the charge discontinued, and the battery be allowed to cool. The total amount of heat units produced is regardless of the rate. At a low rate the ventilation acts for a longer time and the final temperature of the electrolyte will be less. An abnormal rise in temperature coupled with violent gassing indicates that the charging rate is too high.

The subject of ventilation is very important. Hydrogen gas is being evolved from the negative plate very rapidly at the end of the charge. A mixture of 4 per cent. hydrogen is explosive, and a spark is nearly always present to explode it. If a sufficient flow of air is provided across the top of the cells the gases evolved will be carried off. Cells are safe from explosion if the ventilation is adequate. Very little acid is carried off from the electrolyte by the air current, and in the enclosed type of cell, with a moisture trap, the amount of water removed has been greatly reduced. However, over ventilation causes a needless waste of water from the cells. Caution should be used, therefore, to provide just enough ventilation to cause a marked air current across the tops of all cells.

Experiments have proved that soon after the charge is stopped the gassing ceases. No gas is given off from the

plates, and only small bubbles trapped in the electrolyte or pores of the plates are evolved.

Since it is impossible to gradually reduce the charging rate as the sulphate in the plates is reduced, as explained under theoretical charging, the practical method of charging is to start at a predetermined rate and when the plates reach the gassing point reduce the current and finish at this lower rate.

A battery can be charged at a high rate as desired, up to the gassing point. The different methods all accomplish the same purpose, except that some methods charge the battery in a much shorter time than others.

The ordinary method is to start at the 5-hour discharge rate. Continue at this rate until gassing occurs, usually after 4 hours, then cut the rate one-half and continue for 2 hours, when the gravity and voltage will usually have reached a maximum.

The principle of the time-saving methods is to keep the rate of charge equal to the ampère hours out of the battery.

One method is to start the charge at a rate of current a little less than the number of ampères out of the battery, and continue with this current until gassing occurs, then reduce to the 8-hour discharge rate and finish.

Charging at the maximum rate, *i.e.*, charging current just less than ampère hours out of the battery, the percentage of full charge of the battery after one hour is,

Battery 25 per cent. discharged, 93 per cent. charged,
Battery 75 per cent. discharged, 67 per cent. charged,
Battery 100 per cent. discharged, 50 per cent. charged.

A good method in which to charge in a short time as possible is by means of the constant-potential method, in which the charging current is raised sufficiently to bring the voltage of each cell to about 2.3, and is maintained at that rate by reducing the current. Theoretically when the voltage has reached its maximum the charging current will be zero.

Raise the voltage as high as possible by starting at a high rate as is permissible, and hold the voltage constant for two hours, when 90 to 95 per cent. of the charge will have been

put in. No definite rates can be given for this method, because the voltage will vary in each battery due to impurities in the plates, to grounds, acid concentration, and the state of health of the plates.

During ordinary charges the sulphation of the plates is not all reduced. Some cells, due usually to excessive sulphation on discharge or to hard plates, will not come up with the others. To charge the battery as fully as possible, reducing all the sulphate, and to bring all the low cells up, periodical equalizing charges are given. This consists in charging at the finishing rate for two hours after the voltage and specific gravity have reached a maximum. The frequency of the equalizing charge depends upon the amount of work the battery has done and upon the time element. After six or seven discharges an equalizing charge should be given, but if the battery has been idle or has done very little work the equalizing charge can be given at monthly intervals. During an equalizing charge regard must be paid to temperature. The energy put in that is not absorbed chemically becomes heat. It is often good practice to allow the battery to cool after the ordinary charge before the equalizing charge is started. Considerable gas is evolved during this charge.

DISCHARGE.

The discharge rate of a battery is only limited by the capacity of the external conductors. A battery may be discharged by short-circuiting, without harm. The normal discharge rate, on which is based the normal capacity, is usually the 8-hour rate for commercial batteries and the 5-hour rate for batteries used on shipboard.

The discharge of a battery must be stopped when it has reached the low-voltage limit. The low-voltage limit (1.75 volts per cell for 1.210 acid, 5-hour discharge rate) depends upon the type of cell, the concentration of the acid, and the rate of discharge.

Batteries operated with high acid will have a lower voltage

limit than batteries operated with low acid concentration. A battery discharged at a high rate can be carried to a lower voltage limit than a battery discharged at a long low rate. During high rates of discharge the chemical reactions in the cell are so rapid, forming sulphate in the outer layers of the active material of the plates, making it difficult for the acid to reach the interior portions of the plates and increasing the internal resistance of the cell, the voltage will drop quickly. It may be allowed to drop lower than during a long low discharge, since at a low rate the acid reaches the interior portions of the plates, reduces them to sulphate, and when the voltage limit is reached there is very little capacity left in the plates. Thus it is seen that in a short or high discharge to the voltage limit only a fraction of the capacity of the cell is withdrawn, and the voltage may be carried lower than during a long low discharge, when the cell is more nearly exhausted.

The explanation above also shows why the ampère hours obtained from a battery are greater for a long low-rate discharge than for a short high-rate discharge. If 100 per cent. represents the capacity at the 8-hour rate, 87.5 per cent. will be the capacity at the 5-hour rate, 75 per cent. will be the capacity at the 3-hour rate, 50 per cent. at the 1-hour rate, and 33⅓ per cent. at the ½-hour rate.

Fig. IX shows curves of the initial, average and final, or limiting low, voltage of an average cell. It is to be noted that the higher the discharge rate, *i.e.*, the shorter the time, the lower will be the initial, average and final voltage.

Since during discharge the acid is broken up into H_2 and SO_4, forming water and lead sulphate, or, as it is commonly expressed, "driven into the plates," the density of the acid will fall. This drop in gravity is practically proportional to the ampère hours discharged from the battery. The state of discharge may then be judged by taking hydrometer or "gravity" readings of the electrolyte. If the drop in gravity is .070 for a complete discharge at the 5-hour rate, for a shorter time of discharge than 5 hours the drop will be less,

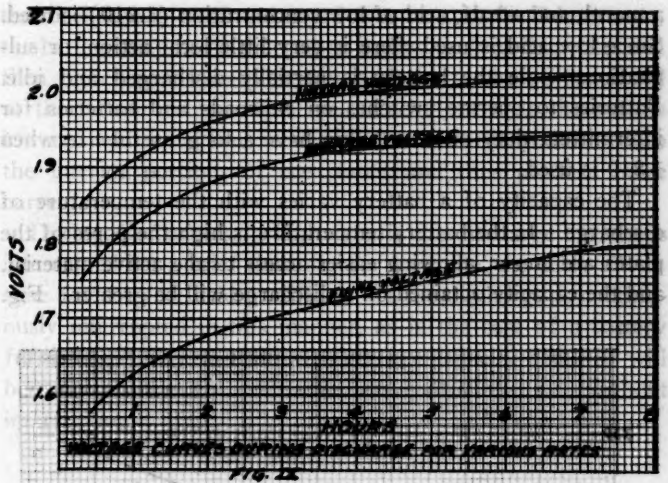


FIG. 22.

and for a longer time of discharge than 5 hours the drop will be more. During a discharge, or at any time when the battery is idle, or is charging, the condition of the battery regarding the capacity can be judged by taking a hydrometer reading.

Always charge a battery, if nothing more than for a short time, as soon after complete discharge as possible. This will prevent abnormal sulphation of the plates.

CHARACTERISTICS OF A LEAD BATTERY.

The capacity and life of a lead type of battery varies greatly with the concentration of the acid used. In the submarine service it is customary to use a density of acid that will be 1.250 on full charge, temperature 80 degrees F. If 1.300 acid is used in the same cell an increase in capacity of 22 per cent. can be obtained. The high acid causes abnormal sulphation, with the consequent loosening of the active material of the plates, and thus shortens the useful life. In automobile service it is customary to use 1.280 acid. In batteries for intermittent use, and in such service that they must stand charged, or partially discharged for long periods of time, such as a month or

a month and a-half, acid of low concentration (1.210) is used. Since low acid is used there is very little local action, or sulphation, while the battery is partially discharged and idle. Batteries to operate switches on railroads and batteries for intermittent duty on board ship have a long useful life when 1.210 is used.

The capacity of a battery varies with the temperature of discharge. If the battery temperature is high the pores of the plates are larger, allowing easier access to the active material, and the capacity obtained on a discharge will be greater. Fig.

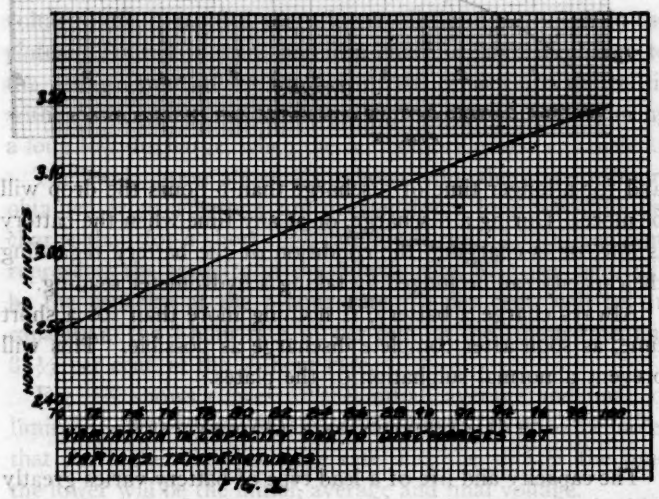


FIG. X

X shows that if the capacity of the battery is 100 per cent. for 80 degrees F. at the 3-hour rate of discharge, the time of discharge is increased to 3 hours 19 minutes if discharged at 100 degrees F., and reduced to 2 hours 50 minutes if the temperature is 70 degrees F. This curve was plotted from actual tests of a pasted type of cell.

After a battery has been discharged at its one-hour rate there is still considerable capacity remaining, since the interior parts of the plates have not been reduced to lead sulphate. If

the discharge is continued at a lower rate, as the 8-hour rate, the battery may be discharged to its low limit at that rate, and then the current lowered again, and the discharge continued at the 5-hour rate, and so on. Each time that the rate is lowered additional time is allowed for the acid to diffuse into the interior portions of the plates, and thus produce more current.

During discharge at a high rate, if the discharge current is interrupted for a brief time, say for a minute, the delay allows time for the free acid to diffuse. If the discharge is continuously interrupted in this manner, as in the case of a battery furnishing power to train a turret, the capacity obtained will be more than if the discharge was continuous, *i.e.*, without interruptions.

DISEASES AND REMEDIES.

A storage battery on board ship can be kept in a healthy condition and full capacity obtained, if:

(*a*) The external connections are kept cleaned by washing them with ammonia solution or soda solution;

(*b*) the battery is discharged only to its low voltage limit;

(*c*) and a charge, or a portion of a charge, is put in soon after discharge;

(*d*) all charges are put in at the proper charging rate, and the rate is lowered when gassing begins;

(*e*) equalizing charges are given at periodic intervals;

(*f*) the ventilation is watched during a charge. See vent traps clear, but not out of the cell (else electrolyte will bubble out) during charging;

(*g*) the plates are kept covered with electrolyte by the addition of pure water;

(*h*) acid is never added to restore the loss of electrolyte, or to bring up a cell low in gravity, except when acid has been accidentally spilled out of a cell;

(*i*) the external connections are kept tight.

Cells may be recognized to be in a poor condition by the voltage falling quickly on discharge. This may be due to

short circuits within the cell. The plates should be withdrawn, sediment removed, separators replaced by new ones if necessary, new acid of 1.180 gravity put in, and the cell charged, and then overcharged for two hours.

COLOR OF PLATES.

When examining the plates of a cell particular attention should be paid to their color. The color of a wet positive plate in good condition varies from a rich dark brown (almost black) if the plate is fully charged, to a reddish brown if discharged. A light grayish coating on the positive plate is not a bad condition if by rubbing with a clean stick a good color is evident immediately under the surface. For dried plates the color is much lighter. Wet negatives are a light slate gray if charged, and darker if discharged. When dry they are considerably lighter, and may be somewhat yellowish if allowed to heat in drying. Irregular color denotes poor distribution of current in the plates.

When negative plates are out of the cell, to prevent injury from heating due to their discharging, they must be immersed in a weak solution of electrolyte, or in water, or water sprayed on them until they are cool.

SULPHATION.

If the plates have not the color as described, and the active material is hard, with white crystals in the pores, the plates are sulphated. It is due to high acid concentration, low charging rates, insufficient charging, or standing discharged. To restore sulphated plates they should be charged and discharged several times.

A sulphated cell will reduce more quickly in low-gravity acid than in high-gravity acid. If the plates are badly sulphated the current of high-charging rates will not break down the sulphate any quicker than current of a low rate. Sulphation, if allowed to proceed, will cause buckling and shedding.

THE ANALYSIS OF BRASS AND BRONZE.

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Non-ferrous alloys have a wide application in naval construction and a considerable variety of such material is submitted for test purposes to the U. S. Naval Engineering Experiment Station, Annapolis, Maryland.

Methods for the analysis of such alloys are numerous and are usually modified somewhat by the analyst in order to adapt them to the exact type of material under examination or to the facilities of the laboratory in which the analysis is carried out.

This paper presents the methods now in use at this Station for the analysis of brass and bronze.

A STUDY OF THE DETERMINATION OF PHOSPHORUS IN PHOSPHORBRONZE.

I.—Introduction.

The usual method employed for the determination of phosphorus in phosphorbronze is long and rather tedious. Also, it involves the use of potassium cyanide, and at one point in the procedure hydrocyanic acid gas is liberated. Both of the last-mentioned compounds are virulent poisons, and extreme care must be exercised by the analyst when using this method. Therefore, a method requiring less time and eliminating the use of potassium cyanide would be very valuable.

In the issue of "Metallurgical and Chemical Engineering" for August, 1914, page 524, Hagmaier describes a method for determining phosphorus in phosphorbronze using cerium chloride as the precipitant for the phosphorus. The directions which he gives for carrying out this determination are

somewhat brief, so that it seemed desirable to try out the method on alloys of known phosphorus content in order to establish the proper working conditions and the limits of accuracy for the determination. Also, the possibility of making a direct precipitation of the phosphorus as ammonium phosphomolybdate without first removing the other constituents of the alloy seemed worthy of investigation.

The work herein described was carried out in order to determine the availability of each of these methods. Both are shorter than the usual procedure and neither requires the use of potassium cyanide.

Hereafter, the method using cerium chloride as a precipitant for the phosphorus will be termed the "cerium chloride" method; the method involving the direct precipitation of the phosphorus as ammonium phosphomolybdate will be called the "direct precipitation" method.

II.—Experimental Work.

1.—Investigation of the Cerium Chloride Method.

The directions for making this determination as given by Hagmaier are as follows:

"Dissolve one gram of the bronze in 10 cc. con. HCl and 5 cc. con. HNO_3 in a tall form 300 cc. beaker. When solution is complete, add 150 cc. of hot water and 10 cc. of a solution of cerium chloride (1 g. cerium chloride, 25 cc. HCl, 200 cc. water). Now add a solution of one part ammonium hydroxide and two parts water, from a burette, stirring continually, until the solution has a greenish blue cast; this will require from 25 cc. to 35 cc. Now add 4 cc. of acetic acid, and boil for 5 or 10 minutes; remove from the hot plate and allow the precipitate to settle; this will require several minutes. Siphon off as much of the clear solution as possible, add 100 cc. of hot water and again siphon. Repeat this washing six or eight times; with careful manipulation all but about 30 cc. of the liquid can be decanted each time without disturbing the precipitate. After sufficient washing add 15 cc. of nitric acid and 3 cc. of

hydrochloric acid and heat until the precipitate has all dissolved. When solution is complete, cool, add 5 cc. (1:1) ammonia, and precipitate the phosphorus.

"By this method the writer has been able to have the phosphorus precipitated in duplicate or three samples in an hour. When this method is used the tin is determined on a separate sample either electrolytically, by titration, or from the combined oxides."

Observing these directions, the following series of experiments were conducted.

Experiments with Alloy Having a High Tin Content.

Experiments were first performed with a high-speed bronze carrying about 11 per cent. of tin and no phosphorus. Preliminary work showed that the addition of the amount of ammonia (1:2) 25 to 35 cc., recommended by the author, caused a flocculent precipitate with a solution of this alloy, even when no phosphorus had been added. The precipitate was undoubtedly tin hydroxide. As the precipitation of the tin with the phosphorus would tend to vitiate one important fundamental of the method, viz: the separation of the phosphorus from the heavy metals, it seemed desirable to determine how much ammonia could be added without causing the precipitation of the tin hydroxide.

Six one-gram samples of the phosphorus free alloy were weighed out and treated according to the standard directions except that the amount of (1:2) ammonia was varied from 8 cc. to 35 cc. The solutions were then examined for the presence of a precipitate. Results are given in the following table:

NH_4OH added, cc.	Character of precipitate.
35	Heavy—Light green.
25	Heavy—Light green.
20	Heavy—White.
15	Heavy—White.
10	Fairly heavy—White.
8	No precipitate.

Having determined, to within 2 cc., the largest amount of ammonia that can be added and not produce a precipitate of tin hydroxide, the next step taken was to endeavor to make a quantitative determination of phosphorus in an alloy containing 11 per cent. of tin when only 8 cc. of ammonia are added.

A sample composed of one gram of the alloy just mentioned and 0.5 g. of $Na_4P_2O_7.10\ H_2O$ was dissolved in 10 cc. HCl and 5 cc. HNO_3, boiled to convert the pyrophosphate to orthophosphate, and then treated according to the standard directions, using only 8 cc. of ammonia (1:2) to neutralize. Result given below.

Phosphorus added, ...	0.0064 g.
Phosphorus found, ...	0.0014 g.

The results show that only a small part of the phosphorus added was recovered, probably due to the small amount of ammonia used. There was also a possibility that all of the pyrophosphate had not been converted to orthophosphate, and hence was not precipitated. In order to eliminate this possible source of error another sample, having the following composition, was analyzed, using 8 cc. of ammonia as in the previous case.

Composition of Sample.

High-speed bronze (11 per cent. tin), .	0.9600 g.
Phosphor-copper (15 per cent. phos.), .	0.0400 g.
Total weight, ...	1.0000 g.
Phosphorus content of sample, . .	0.0060 g.

The result of this determination is indicated by the following data:

Phosphorus added, ...	0.0060 g.
Phosphorus found, ...	0.0015 g.

These data show conclusively that only a small part of the phosphorus is precipitated when 8 cc. of (1:2) ammonia are used.

Having demonstrated that 8 cc. of ammonia are not sufficient to completely precipitate the phosphorus, another experiment was carried out, as follows:

An alloy containing about 11 per cent. of tin and 1.70 per cent. of phosphorus was analyzed for phosphorus according to the standard directions for the cerium chloride method, using 30 cc. of ammonia. The data follows:

Phosphorus content,	1.70 per cent.
Phosphorus found,	1.60 per cent.

This result is fairly satisfactory, but is a little low, and indicates that a tin content of 11 per cent. in an alloy may be considered as marking the upper limit of the usefulness of the cerium chloride method. Further experience with this method has confirmed this conclusion and points to the desirability of not using this method when the alloy contains more than 10 per cent. of tin.

Test with an Alloy Having a Low Tin Content.

In order to gain further information concerning the method, particularly with respect to its application to the more usual type of alloys, viz: those of moderately low tin and phosphorus content, a series of experiments were carried out with a bronze containing 0.34 per cent. tin. Accordingly, four one-gram samples having the following composition were weighed.

Composition of Samples.

Bronze (0.34 per cent. tin),	0.9600 g.
Phosphor-copper (15 per cent. phos.),	0.0400 g.
Total weight,	1.0000 g.
Phosphorus content of sample,	0.0060 g.

Each of the four samples were treated according to the standard directions for the cerium chloride method except

with respect to the amount of ammonia added. The amount of (1:2) ammonia used was 25, 30, 32.5 and 35 cc. respectively. The results are tabulated below.

NH_4OH added, cc.	Phosphorus added, grams.	Phosphorus found, grams.
25.	0.0060	0.00599
30	0.0060	0.00615
32.5	0.0060	0.00599
35	0.0060	0.00590

In all of the above cases the phosphorus was evidently completely precipitated and the agreement between all results is satisfactory. Evidently nothing was gained by the addition of more than 25 cc. of (1:2) ammonia.

It may well be noted at this point that, judging from the color of the cerium phosphate precipitate, small amounts of copper were carried down with the precipitated phosphate when the amount of ammonia exceeded 25 cc. When 25 cc. of ammonia were employed practically no copper was carried down. However, the contamination of the cerium phosphate by the copper did not affect the accuracy of the final results.

2. Investigation of the Direct Precipitation Method.

Two one-gram samples having the following composition were weighed.

Composition of Samples.

High-speed bronze (11 per cent. tin),	0.9600 g.
Phosphor-copper (15 per cent. phos.),	0.0400 g.
Total weight,	1.0000 g.
Phosphorus content of sample,	0.0060 g.

These samples were treated as follows:

Ten cc. of con. nitric acid and 5 cc. con. hydrochloric acid were added and, after the reaction was complete, the solution was diluted with 25 cc. of hot water. Then the solution was

neutralized with ammonia and then made acid with nitric acid. The solution was heated to 90 degrees C., 50 cc. of ammonium molybdate solution added, shaken for 5 minutes, and then allowed to stand at least four hours. The yellow phosphomolybdate was filtered out, washed a few times with the usual acid ammonium nitrate solution (water, 328 cc.; nitric acid, sp. gr. 1.4–162 cc.; ammonium hydroxide, sp. gr. 0.90–35 cc.) and then dissolved in 1:1 ammonia water. Forty cc. of ammonium molybdate solution were then added, the solution heated to 80 degrees C., then made acid with nitric acid, shaken for 5 minutes and allowed to stand at least four hours. The yellow phosphomolybdate was filtered out and washed thoroughly, until free from copper, with the acid ammonium nitrate solution mentioned above. Then the phosphorus was determined in two ways, viz:

(*a*) The yellow ammonium phosphomolybdate was filtered on a Gooch crucible, washed with dilute nitric acid followed by cold water, dried at 104 degrees C. and weighed.

(*b*) The yellow ammonium phosphomolybdate was dissolved in 1:1 ammonia water and the phosphorus precipitated as $MgNH_4PO_4$. The magnesium ammonium phosphate was filtered out, washed with dilute ammonia water, dried and burned to $Mg_2P_2O_7$ in the usual manner. Results were as follows:

Weighed as	Phosphorus added.	Phosphorus found.
$(NH_4)_3PO_4.12MoO_3$	0.0060 g.	0.00591 g.
$Mg_2P_2O_7$	0.0060 g.	0.00574 g.

These results are satisfactory and indicate that the determination of phosphorus by this method can be made with a requisite degree of accuracy, even in the presence of a high percentage of tin.

Further, the result obtained by weighing the phosphorus as ammonium phosphomolybdate was equally satisfactory as that obtained by weighing the phosphorus as magnesium pyrophosphate. As a general rule, however, the latter procedure is recommended, because of the greater stability of the pre-

cipitate and because its exact composition is more accurately known.

Later work with this method has shown that satisfactory results may be obtained with 1.75 per cent. of phosphorus in the presence of 13 per cent. of tin.

III.—Conclusions.

1. Two methods for the determination of phosphorus in phosphorbronze have been investigated. Both methods were found to be satisfactory within certain limits and these limits were defined. Both methods are more rapid than the usual standard method and neither require the use of potassium cyanide.

2. The original directions as given for the determination of phosphorus by the cerium chloride method are satisfactory. It seems advisable, however, to always add at least 30 cc. of ammonium hydroxide.

3. The cerium chloride method for phosphorus will give satisfactory results when the tin content of the alloy does not exceed 10 per cent. When the tin content of the alloy exceeds 10 per cent. the results tend to be low.

4. Proper conditions for the direct precipitation of the phosphorus with ammonium molybdate, in the presence of all the metals comprising the alloy, have been established.

5. The direct precipitation method for phosphorus will give satisfactory results with a tin content of an alloy as high as 13 per cent. Experiments with a higher percentage of tin have not been performed.

Methods for the Analysis of Brass or Bronze.

There are at least two features of any analytical procedure that are of primary importance. These features are accuracy and rapidity.

For the examination of any class of substances there are usually several methods of procedure available, each procedure having its own degree of the characteristics mentioned above. In the majority of cases the most accurate analytical proced-

ure is required and such a process usually requires more time than some other process giving a lesser degree of accuracy. There are cases, however, when rapidity is of greater importance than extreme accuracy. When such cases present themselves the analyst must choose the most rapid procedure that will give the requisite degree of accuracy.

The following pages contain the result of an effort to provide "written standard instructions" for the analysis of brass or bronze. Two complete analytical procedures have been given: the "Standard Methods" giving a high degree of accuracy and moderate speed; the "Rapid Methods" giving a moderate degree of accuracy and high speed.

No originality is claimed for the fundamentals of any of the methods hereafter described. Many of the methods have, however, been modified to suit the requirements of the work and resources of the laboratory. The "Rapid Methods" are, with a few variations, those given by Lee, Tricky and Fegely in "The Journal of Industrial and Engineering Chemistry," Vol. VI, page 556 (1914).

Standard Methods for the Analysis of Brass or Bronze.

Tin.

Place one gram of the alloy in a 250 cc. beaker, cover with 5 cc. of water and then add 10 cc. con. nitric acid. When violent action has ceased place on hot plate and evaporate to dryness. Moisten residue with con. nitric acid and add about 100 cc. of water. Bring to boiling, taking care that it does not bump, and continue boiling for 5 minutes. Stand aside and allow to settle for at least one hour. Filter, wash first with dilute nitric acid and then with hot water. Dry, and and ignite to constant weight in a porcelain crucible. From weight of the SnO_2 calculate the weight of Sn.

If the percentage of tin is small, less than 1 per cent., it is usually unnecessary to purify the SnO_2. However, the SnO_2 always carries some copper oxide and small amounts of oxides

of other metals present in the alloy. When the percentage of tin is greater than 1 per cent., the SnO_2 should be purified as follows:

After weighing, the precipitate is mixed with 10 to 12 times its weight of a mixture consisting of equal parts of anhydrous sodium carbonate and pure sulphur, and then the mixture is heated in the covered crucible over a small flame until the excess of sulphur is almost entirely removed. This point is easily recognized by there being no longer any odor of SO_2 and no blue flame of burning sulphur evident between the cover and the crucible. After cooling, the melt is treated with a little hot water, whereby the tin goes into solution as sodium sulphostannate together with some copper and tin. The deep brown liquid, therefore, is treated with sodium sulphite solution until it becomes only slightly yellow in color, after which any iron or copper, etc., will be quantitatively precipitated. The latter are filtered off and washed, first with water to which a little sodium sulphide has been added and, finally, with hydrogen sulphide water. Dry, ignite and weigh. Subtract weight of combined oxides from the weight of the impure stannic oxide to get the correct weight of the latter. Dissolve the oxides in dilute nitric acid and add the solution to the filtrate from the stannic oxide.

MANGANESE.

If manganese is present in the alloy it is determined at this point by the Williams Method (Blair, seventh edition, page 118). The filtrate from the tin or the solution which contained no tin is evaporated until sirupy and salts begin to crystallize. Do not take to dryness. Add 50 cc. con. nitric acid and bring to a boil. Remove from the hot plate and immediately add a small crystal of potassium chlorate and then a little more potassium chlorate, and continue until about two grams have been added. Put on hot plate and boil until all chlorine is driven off. Filter on an extra heavy mat of asbestos, and wash with hot water, doing it entirely by decantation. Put precipitate back into beaker and wash down

funnel with an approximately N/10 solution of ferrous sulphate, using an accurately measured quantity. Warm slightly until all the MnO_2 is dissolved, and titrate the excess ferrous sulphate with standard potassium permanganate solution. A blank should be run each time on the ferrous sulphate, treating exactly the same as in the determination. For calculation of results see Blair.

LEAD.

To the filtrate from the preceding determination add 5 to 10 cc. of con. sulphuric acid and evaporate to strong fumes of SO_3. Cool, add 100–200 cc. of water, and, after stirring, 25 cc. of ethyl alcohol. If desirable, heat gently to hasten the solution of the salts. Allow to stand for at least one hour and then filter, using a Gooch crucible. Wash, first with water containing 1 per cent. sulphuric acid and 25 per cent. alcohol, and then with pure alcohol until free from acid. Dry and weigh in the usual manner. From weight of $PbSO_4$ calculate the percentage of Pb.

COPPER.

Concentrate to suitable volume. Add ammonia slowly, with stirring, until just alkaline as shown by the deep blue color. Then add 5 cc. con. sulphuric acid and electrolyze for copper.

IRON AND ALUMINUM.

Boil the filtrate from the copper after adding a few drops of con. nitric acid. Continue heating until solution has been concentrated to suitale volume. Then precipitate the iron and aluminum with ammonia in the usual manner. If more than a small amount of these metals is present the precipitate must be dissolved in hot 1:1 HCl and then reprecipitated in order to completely separate them from the zinc. (*Note.*—If the alloy is very high in zinc, it is well to add a few grams of ammonium chloride before precipitating the iron and aluminum hydroxides.) Dry precipitate and burn to oxide. If only iron is present, weigh as Fe_2O_3 and calculate to metallic

iron. If aluminum is present, weigh as $Fe_2O_3 + Al_2O_3$. Fuse the combined oxides with anhydrous $KHSO_4$ until all are dissolved. Cool and dissolve the melt in about 100 cc. of water containing 5 cc. of sulphuric acid. Run through a Jones reductor and titrate iron with standard potassium permanganate solution. Calculate to metallic iron. Get aluminum by difference.

Zinc.

Concentrate the filtrate from the iron to about 250 cc. During the concentration process add 20 g. of ammonium chloride. Remove from hot plate, add 2–4 drops of methyl orange and render just slightly alkaline with ammonia. Then render faintly acid with dilute sulphuric acid. The solution should be so faintly acid that the subsequent addition of microcosmic salt solution will render it faintly alkaline. Inasmuch as zinc ammonium phosphate is soluble in both acid and alkali, it is essential that this point be very carefully regulated. Then, while the solution is still hot, add slowly with constant stirring, 50 cc. of a saturated solution of microcosmic salt (160 g. per liter). A bulky precipitate of zinc ammonium phosphate is immediately thrown down which soon becomes crystalline. Allow to stand for at least two hours, preferably over night, and then filter on a Gooch crucible which has previously been ignited at full heat of a Meeker burner. Wash thoroughly with hot water. Dry at 105 degrees C. and then ignite slowly over a small Bunsen flame. When the odor of ammonia can no longer be detected increase the heat to that of a full Bunsen flame for at least 15 minutes, and finally ignite at full Meeker flame for 5 minutes. Cool and weigh as zinc pyrophosphate, $Zn_2P_2O_7$. Calculate Zn.

Rapid Methods for the Analysis of Brass or Bronze.

Tin (and Antimony).

Weigh 0.5 gram of the alloy into a 400 cc. beaker, add 5 to 10 cc. dilute nitric acid (1:1), cover with a watch glass until violent action ceases, then remove cover and evaporate to

a paste on hot plate. Add 15 cc. dilute nitric acid, boil for several minutes and dilute to about 200 cc. Boil for a few minutes, filter through a weighed Gooch crucible, wash with hot nitric acid wash, and then with hot water. Dry the crucible and contents on hot plate and then ignite at red heat for 10 minutes. The ignited residue consists of SnO_2 and any Sb (as Sb_2O_4) which may have been present in the alloy.

Notes.—The results obtained by this method are usually a little high, owing to the fact that the precipitate frequently contains traces of the oxides of copper, antimony and lead. However, the digestion of the dried residue in dilute nitric acid and final separation of the precipitate from a large volume of solution tend to reduce errors from this source. The precipitate will also contain any phosphorus that is present in the sample.

2. Much time and energy were consumed in an effort to obtain a volumetric method for determining tin in a separate portion of the alloy. One of the most attractive volumetric methods for making this determination is Walker and Whitman's modification of Low's iodimetric method. Our efforts, however, to adapt it to our scheme of analysis were without success. The chief obstacle to its application to the rapid analysis of bronze is the presence of relatively large percentage of copper in the alloy. The method, however, was found to give excellent results when used in making analyses of Babbitt metal if the copper in the alloy was small; but if the percentage of copper was large the results came high, owing to the fact that during the reduction of the tin the copper was reduced to cuprous chloride which takes up a portion of the iodine when the solution is finally titrated. Our results in regard to the errors introduced by the titration of tin in the presence of copper agreed with those obtained by Ibbotson and Aitchison.

LEAD.

To 0.5 gram of the alloy in a 300 cc. Erlenmeyer flask, add 12 cc. of water containing 4 grams of tartaric acid, and then

4 cc. of con. nitric acid. Place on a hot plate to dissolve the alloy quickly. (The solution should be perfectly clear; if not, reject it and repeat the procedure.) Remove the solution from the hot plate, allow to cool for one to two minutes, add 10 cc. con. sulphuric acid and then heat on hot plate until all nitrous fumes are expelled. (*Caution.*—Care must be exercised not to carry the procedure beyond this stage or the tartaric acid will be decomposed.) Dilute with 100 cc. cold water, add 75 cc. ethyl alcohol, shake, allow to stand for 2 or 3 minutes, filter through a weighed Gooch crucible, wash with water to which a little sulphuric acid has been added, until the precipitate is white, and then wash out acid with alcohol. Reject the filtrate. Dry the precipitate in a crucible on hot plate, and then heat to dull redness with the Bunsen burner for a few minutes. Cool and weigh as $PbSO_4$.

Notes.—1. In order to prevent occlusion and adsorption of the copper salts by the lead sulphate precipitate, it was found necessary to make the solution from which the lead precipitate was separated by filtration relatively large. The solution of the lead sulphate is prevented by addition of alcohol.

2. In case the alloy contains a small percentage of lead it is advisable, of course, to use a relatively large amount of the sample. If this is done, the quantities of the reagent employed, including water and alcohol, should be increased proportionately. The reasons for this procedure are obvious. In the first place, unless the volume of the solution is made larger the concentration of the copper and other metals present becomes very large, owing to use of large amounts of the sample. This will increase the error due to occlusion and adsorption as mentioned in Note 1. In the second place, in order to preserve the proper concentration of sulphate ions for the complete precipitation of lead in this larger volume of solution it is necessary to use larger amounts of the reagent, sulphuric acid.

Copper.

Place 0.5 gram of alloy in a 400 cc. beaker, add 5 to 10 cc. of dilute nitric acid (1:1), cover beaker with a watch glass

until violent action ceases, then remove watch glass and evaporate on hot plate to a sirupy consistency. Dilute to about 200 cc. and add KOH solution until a small precipitate of copper hydroxide persists after thorough stirring. Now add acetic acid until the copper precipitate is completely dissolved, then add a small excess of the acid. Cool the mixture to tap-water temperature, then add 3 to 4 grams of potassium iodide crystals. When the potassium iodide is completely dissolved titrate the liberated iodine with N/10 sodium thiosulphate solution, using starch solution as indicator. The thiosulphate solution should be standardized on metallic copper, the copper content of which has priviously been determined electrolytically.

Notes.—1. It has been pointed out by Walker and Whitman that the results obtained by following Low's iodine method are uniformly a little low. They add "that this error is not due to the method, which gives exceedingly accurate results, but to the fact that nearly 6 per cent. of the copper is not precipitated as cuprous oxide. This loss is uniform, for if you add 6 per cent. of the copper determined, the result will be the per cent. of the copper in the alloys." This is undoubtedly true. Their further statements, however, that when an alloy containing 5 per cent. of copper is decomposed by nitric acid, evaporated to dryness, taken up with nitric acid and filtered, the error in determining the copper in the filtrate will frequently be 0.5 to 0.7 per cent., cannot be confirmed by our experience. By following the proposed method of standardization and analysis, which is essentially Low's method, we have been able to check to within 0.1 per cent. repeatedly.

2. Provision has not been made in the method as formulated for the separation of copper from any other metals, yet care must be exercised to exclude from the solution prepared for titration any substances which will either liberate or absorb iodine. Therefore free Cl, free Br, nitrous oxides, ferric ions, and As and Sb in the "ous" condition must be absent.

Ferric ions must be removed by adding ammonium fluoride,

which interacts with the former to produce ferric fluoride. This latter substance, which is only slightly ionized, has little or no oxidizing power and, therefore, cannot liberate iodine under the existing conditions.

The trivalent As and Sb, if present, must be oxidized to the pentavalent condition by the addition of Br. Excess of Br must be removed by boiling the solution before titrating. No other elements interfere with the procedure.

3. Lead, bismuth and cadmium, if present, interact with the KI and form the corresponding yellow, insoluble iodides. This causes no trouble, however; in fact, many chemists regard the presence of one or more of these elements as a distinct advantage, as the presence of the yellow precipitate assists the operator in securing uniform end points. In this laboratory it is customary to add a few cc. of a solution of lead acetate to the solution to be titrated if it is known that lead is not present.

4. In order that the liberated iodine may be held in solution it is necessary to use rather large excess of KI. This procedure increases the speed of the reaction.

5. The presence of an excess of inorganic acid interferes with the procedure. It should be remembered, however, that unless the solution contains a sufficient excess of acetic acid the end point will not be sharp.

6. The solution should always be cooled to tap-water temperature just before the KI is added.

7. It should be remembered that the tin present will make an insoluble residue in the solution prepared for titration.

ANTIMONY.

Weigh 0.5 gram of fine drillings of the alloy into a 300 cc. Kjeldahl flask, add 25 cc. of con. sulphuric acid and heat over the bare flame of a Bunsen burner. Keep the acid at its boiling point until the solution is clear or the residue is white. Cool, add 100 cc. water, boil for several minutes and transfer the contents of the flask to a 400 cc. beaker. Dilute to 200

cc., heat to 70 degrees C. (158 degrees F.), and titrate with a standard potassium permanganate solution. The permanganate solution should be added rapidly until the permanganate color persists, then add several cc. in excess. Stir the solution vigorously, and then titrate with a standard solution of ferrous ammonium sulphate until the color just disappears.

Notes.—1. Although antimony is not found in the majority of bronzes and brasses it frequently occurs alloyed with variable percentages of lead, tin, copper and iron. Therefore, in order to make the present scheme of analysis as wide as possible in its application and thereby increase its usefulness, it was deemed advisable to incorporate a method for the rapid determination of antimony.

2.—The method is at once recognized as a modification of Low's well known method. The chief difficulty we experienced in fitting it to our scheme of analysis was the matter of securing antimony in a suitable condition in a sulphuric acid solution. Alloys containing a high percentage of copper resist solution by the usual procedure. Nitric acid is eliminated as a solvent because of its oxidizing action; and HCl and $KClO_3$ are ineffective unless the treatment is greatly prolonged. Finally, the not entirely satisfactory method of decomposing the alloy in con. sulphuric acid in a Kjeldahl flask exposed to the bare flame of a Bunsen burner was adopted. Complete decomposition may usually be obtained in 10 to 20 minutes, after which the determination may be readily finished in 10 minutes.

After one or two trials, it will probably be found that the blue color imparted to the solution by the presence of copper does not hinder the determination of the exact end point when the permanganate is added.

3. Demorest has pointed out in an excellent paper that it is necessary to employ a large excess of potassium permanganate to complete the oxidation of the antimony. It is not best to have HCl present when antimony is titrated, as the end point is made very transient by its presence.

Iron and Zinc.

To a 0.5 gram sample of the alloy in a 400 cc. beaker add sufficient dilute nitric acid (1:1) to dissolve the sample. Heat on hot plate until the alloy is thoroughly decomposed, then evaporate the solution just to dryness, add 10 cc. con. HCl and 100 cc. of water, heat to about 70 degrees C. and pass H_2S through the mixture until all the Pb, Sn and Sb (and Cd, etc.) are precipitated. Filter, using a Büchner funnel with asbestos mat, wash the precipitate with water. The filtrate which contains the iron and zinc should be transferred to a 500 cc. beaker.

Note.—A drop of this filtrate should be transferred to a spot plate and tested with a drop of potassium ferrocyanide for the presence of copper, which is an interfering substance and, if present in weighable quantities, should be removed. If copper is present, which will be indicated by the presence of a red coloration, treat the filtrate again with hydrogen sulphide and filter.

Add 2 cc. of con. nitric acid to the filtrate to oxidize the iron, heat to boiling, add 25 cc. of 5N ammonium chloride solution and then ammonium hydroxide until the odor of the reagent barely persists after boiling the mixture for one minute. Filter off the $Fe(OH)_3$, wash and ignite. Weigh as Fe_2O_3.

Concentrate filtrate to 200 cc., heat to 70 degrees C. and titrate with standard potassium ferrocyanide using ferric chloride or uranyl nitrate as an indicator. The titration should be performed slowly and with constant stirring in order to obtain the most satisfactory results. Continue to add the ferrocyanide until a drop of the solution in the beaker shows a bluish tinge (brown tinge when uranyl nitrate is used as indicator) when tested on a white porcelain plate with a drop of ferric chloride after standing a few seconds. The quantity of the standard which is required to produce a good end point in the blank determination made at the time of standardizing the solution must be subtracted from the amount of standard used in making the determination.

Notes.—1. Correction for blank.—As the indicators are not very sensitive under the imposed conditions it is necessary to determine the excess of standard solution required to effect the color change of the indicator used. A "blank" must be run, therefore, using the same quantities of reagents under the corresponding conditions of volume, temperature and acidity.

2. Zinc is completely precipitated from hydrochloric acid solution by potassium ferrocyanide as white zinc ferrocyanide. Such metals as lead, copper, tin and manganese are also precipitated by this reagent, and therefore must be removed before the zinc is titrated.

3. The acid solution must not contain free chlorine, free bromine, or the oxides of chlorine, as these substances decompose ferrocyanide.

4. Care must be taken to conduct the standardization as well as all determinations under corresponding conditions with particular reference to volume, temperature, acidity, amount of ammonium salts and the rate of titration. Furthermore, it is imperative that the titration be conducted slowly and with constant stirring of the solution. If this precaution is not observed the end point will be reached apparently before all the zinc is precipitated.

NOTES.

OIL FUEL.*

By ERNEST H. PEABODY,

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The use of oil fuel for marine purposes comprises essentially the burning of oil in the furnaces of steam boilers. A limited amount, it is true, is consumed in the cylinders of internal combustion engines, and the scope of the latter in marine service will be considered in another paper before this Congress.

But it was tersely stated a few years ago by Prof. Lionel S. Marks of Harvard University that the history of the internal combustion engine has yet to be written. It is being written—with ingenuity, patience and zeal, but with no great progress toward large powers, and the steam-driven motor, with all its limitations, still stands preeminent in the field of power development.

The "Steel Age" and the "Age of Electricity" have only widened the sphere of Steam, on which they depend, and until some predestined genius shall convert the heat of the sun directly into work, or until the "Ray" foretold by Kipling shall really come into conscious being, along with his "cloud piercing searchlight," steam boilers are likely to be used in larger units and in multiplying numbers, and oil fuel for marine purposes confined largely to the generation of steam.

OIL DISCOVERY AND PRODUCTION.

The discovery of oil shale in Colorado and Utah, in 1912, has re-awakened interest in a valuable paraffin oil, the manufacture of which in the United States, while profitable for a time, early succumbed to the lower price of crude petroleum. Shale oil has, however, continued to be produced in France and Germany, and especially in Scotland, where in 1913 more than three million tons of shale were distilled, producing over a million and a half barrels of oil, and a very large amount of ammonium sulphate. The beginning of this industry is closely allied with early developments in the production and refining of petroleum, for it was the exhaustion of a petroleum "spring," and later of a special coal supply used for making paraffin oil, that led to the distillation of shale.

In December, 1847, Mr. James Young, a noted chemist of England, was informed of the existence of a spring or seepage of crude oil at Alfreton, Derbyshire, in connection with the working of coal deposits. He experimented with the oil and devised a method of distilling paraffin oil from the crude. The oil "spring" soon went dry, but on the theory that the oil had been produced from the coal by a distillation process in the earth at low temperature, Young set out to produce a paraffin oil from coal by artificial methods. He succeeded with a special gas coal found in West Lothian, and established a profitable business in illuminating oil, the process being based on the famous patent granted to Young in England in 1850 for the low temperature distillation of coal. The process was later patented in America.

The discovery of the oil spring worked by Young was not an isolated

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case, and we need no other testimony that petroleum was known to the ancients than the references in the Bible, notably that which appears in the XXIX Chapter of Job: "And the rock poured me out rivers of oil." (The name petroleum is, in fact, derived from two Latin words; *petra*, rock, and *oleum*, oil, meaning "rock oil.")

The historic temple of the Ancient Fire-worshippers at Surakhany, on the Apsheron peninsula, near the shores of the Caspian Sea, and not far from Baku, was situated right on the edge of the famous oil fields of Russia, and doubtless the outcroppings of petroleum, as well as the natural gas for supplying the "eternal fires," were known to the devotees who visited this temple many centuries ago. Marco Polo in the 13th century says of the Baku fields, "there is a fountain from which oil springs in great abundance inasmuch as a hundred shiploads might be taken from it at one time. This oil is not good to use with food, but is good to "burn."

Oil is spoken of by Herodotus, Plutarch, Pliny and many other ancient writers.

Still further testimony of the early knowledge of petroleum is furnished by explorers of America who traveled through New York, Pennsylvania and the Middle West in the 18th century, and who reported the burning of crude oil in the religious rites of the Indians, and its use by their medicine men for curative purposes. One of these travelers, Peter Kalm, of Russia, even published a map showing the oil springs of Pennsylvania, on his return from a visit to America in 1748.

Thus, outcroppings of rock oil were of common repute in various parts of the world when Young began work on the Alfreton spring, and, not only that, but paraffin had been produced from bitumen some twenty years before, and kerosene or "coal oil" had already been distilled from coal in both Germany and France. But the principal uses for petroleum were for rough lubricating purposes, rude torches and for alleged "cures" more or less on the patent medicine basis, so that Young's achievement in producing paraffin oil as an illuminant on a commercial basis is of historic interest, as it pointed the way for the profitable utilization of petroleum and stimulated the search for oil in greater quantities.

In 1854 the Pennsylvania Rock Oil Company was organized in New York for the avowed purpose to "raise, procure, manufacture and sell Rock Oil," and a report on a sample of oil from Venango Co., Pa., made for the company by Professor B. Silliman, of Yale University, in April, 1855, not only marked the American professor of chemistry as a widely-read and well-informed student of the known oil-fields of the world, but gave a fractional distillation of petroleum which clearly indicated its marvelous value to mankind. But the embryonic industry languished until some of the more pertinacious promoters of the oil company formed the Seneca Oil Company and started digging operations under the supervision of "Colonel" E. L. Drake, on some land leased from the parent company.

Then occurred one of those inspired applications of old ideas to new problems which convert comparative failure to success with revolutionary effects. Artesian wells had been drilled to considerable depths, some for the purpose of obtaining salt. One of these, 400 feet deep, owned by Kier of Pittsburgh, accidentally produced a limited amount of petroleum which was bottled and widely sold for medicinal purposes. This appears to have suggested to Mr. George H. Bissel, a promoter of the original oil company, and an enthusiastic backer of the well-digging scheme, to apply the artesian-well drilling idea to the search for oil.

Drake at once saw its possibilities and with much ingenuity applied the then untried method of sinking an iron pipe through the super strata of earth to bed rock and operating the drill through the pipe, and in August, 1859, on Oil Creek, Pa., he "struck oil" at a depth of 69 feet.

Although a small trade in petroleum had existed for many years at Baku, and considerable oil had been produced in Roumania from hand-

dug wells, the real oil-producing and refining industry started when oil commenced to flow from Drake's well, and the production went forward with a tremendous impulse, ever increasing in amount from that day to this. The statistics of the inserted table were compiled by the U. S. Geological Survey, and are reproduced from their published reports.

USE OF OIL AS FUEL.

The decade following the advent of Drake's well is marked by considerable activity in inventions of methods for utilizing oil as fuel for power purposes, and its adaptability to marine usage is emphasized by the experiments of the United States Navy under Commodore Isherwood, and of the British Admiralty under Admiral Selwyn. In the Baku region also, on the Caspian Sea, and on the Volga, where, owing to the character of the oil and the cruder methods of refining, a large proportion of the oil was available for fuel, the subject received serious attention; though, previous to 1870 much of the *astatki* (or "leavings") was disposed of by burning in open pits. During this period all the Russian wells were hand dug, the deepest being not over fifty feet below the surface; but a new era began in '71 with the drilling of the first well on the Balakhany plateau and the appearance of the first Baku "gushers." In 1874, the Russian Government adopted oil fuel for all vessels of the Caspian Fleet, and the year following, Robert and Ludwig Nobel (brothers of the celebrated engineer and chemist who founded the Nobel Prizes,) lent a great impetus to the Russian oil industry by improving the refining methods, building pipe lines, tank cars, tank vessels, etc., and barges for carrying oil on the Volga River.

The remote position of the Baku fields and the lack of really adequate transportation facilities, however, greatly limited the introduction of Russian fuel oil to other countries, except possibly in Persia. On the other hand, American oil was very valuable for refining, and while a considerable amount was devoted to fuel purposes, and many types of steam-atomizing oil burners came to be used in regions near the oil fields as the production gradually spread from Pennsylvania to West Virginia, Ohio, Indiana, etc., still the bulk of the oil went into the manufacture of illuminants, lubricating oils, paraffin, etc., and practically none was available for fuel for marine installations.

This was the situation in 1893, when Colonel Nabor Soliani of the Royal Italian Navy presented his comprehensive paper, "Oil Fuel for Marine Purposes," before the Division of Marine and Naval Engineering and Naval Architecture of the International Engineering Congress held in connection with the World's Columbian Exposition at Chicago. The high cost of coal in Italy and the comparative accessibility to the Baku oil regions were factors which led to early experiments with oil by the Italian Navy, and the advantages of the use of what Colonel Soliani called "naphtha refuse" and the successful application of various types of "pulverizers" (all of which were of the steam-atomizing type) were clearly pointed out in this able paper.

Outside of Russia and the few points where Baku oil was obtainable and excepting in a very limited field in America, "oil fuel," as such, was not in evidence at this period. It was even currently reported, with no great exaggeration, that the Standard Oil Company burned coal under their boilers and not oil.

Such was the state of things, when in January, 1901, Captain A. F. Lucas drilled his sensational well near Beaumont, Texas—known as Spindle-top. Elsewhere in this paper, I am fortunate in being able to give a brief description by Captain Lucas himself of the discovery of this wonderful oil field.

Spindle-top marks a distinct epoch in the history of oil fuel. The tremendous capacity of the "gusher" (over 100,000 barrels a day), a character of oil ideal for fuel purposes, the proximity to the coast, facili-

tating easy transportation, and the resulting "boom" in drilling which still further increased the supply, all combined to place "fuel oil" on a basis of permanency which it has held for fifteen years, and which today seems to be more than ever assured.

Coincident with the development of the Texas oil field, and largely on account of it, the California fields, which had already had a healthy growth, forged rapidly ahead, and in 1903 this State assumed the position of the first of the oil-producing States, which distinction it has since held unchallenged. California oil is largely of a character which makes it available for fuel, so that, with the Beaumont "gushers" to supply the East and California to supply the West, oil fuel became the all-absorbing subject among power users in America, and the interest rapidly spread to other countries. Everybody who had an oil burner to sell began to haunt the presence of the prospective user and to claim the usual "ten per cent." superiority over his competitors—new designs and new inventions of "burners" sprang into existence—oil-fuel installations began to be made on a large scale and the importance of the movement led some of the large manufacturing and engineering companies to make careful investigations and prosecute valuable experimental studies of methods of oil burning. What is especially noteworthy, interest in oil as a fuel revived in marine circles, and oil fuel began to be used aboard ship. A considerable number of notable marine installations were made at this time; among others, several by the New York Shipbuilding Company under the direction of one of the pioneers of the art of oil burning on shipboard in this country, Mr. Luther D. Lovekin. These vessels were operated on the Pacific Coast, and were very successful and the objects of much comment.

In 1901 the late Rear Admiral George W. Melville, U. S. N., then Engineer-in-Chief of the Navy, impressed by the great output of oil at Spindle-top, and convinced that oil was destined to play an important part in military achievement, appointed a special board of naval officers, under the able direction of Commander (now Rear Admiral) John R. Edwards, to investigate the "relative value of oil and coal as a fuel for naval purposes." The report of the exhaustive investigation of the subject by this Board, published in 1904, has long been considered the most valuable and complete treatise of its kind.

Undoubtedly the activity in the fuel-oil field resulting from the great production of oil in Texas and California during the five years following the discovery at Spindle-top, together with the attention given the subject by our Navy, reawakened the active interest of the British Admiralty, to whom we are indebted for inaugurating the present widespread use of the mechanical atomizer.

WHAT IS FUEL OIL?

The *origin* of petroleum can hardly be considered an important matter to prospective users of fuel oil. The question whether it is animal, vegetable or mineral, or all three (which seems likely), organic or inorganic, belongs rather to the province of the geologist to decipher. Those interested may refer to the scientific papers on this topic, published in the Transactions of the American Institute of Mining Engineers for 1914, and I understand also that a paper is to be presented at the Fourth International Petroleum Congress at San Francisco, 1915, by Dr. David T. Day, of the U. S. Bureau of Mines, which will settle the controversy—probably. But the available supply of oil and prospects of its continuance are of prime importance to the vessel owner who contemplates using oil as a fuel.

Let us consider then: In the first place, what is "fuel oil?" We are told that petroleum consists of very many combinations of carbon and hydrogen or hydro-carbons, which, while they may be entirely sim-

ple to the chemist, seem extremely complicated and abstruse to the lay mind, as for example, Propane ($CH_3.CH_2.CH_3$) or Dimelhylpropylmethane $(CH_3)_2$. CH (CH_2. CH_2. CH_3) or Hentriacontane (C_{31} H_{64}).

How much of this intricate product may we expect to be turned over for use as "fuel oil?" I have asked Doctor Day to answer this question, and am indebted to him for the following statement:

"From the standpoint of the petroleum trade, fuel oil, in general, includes all oils which are not saleable for some other special purpose at a higher price than that which prevails for oils to be sold as fuel oils, or to be burned under boilers. From the trade point of view, it also includes special distillates which are sold as Diesel oils. It does not include various distillates burned for power purposes, such as gasolene, naphtha, motor spirits, and various kerosene distillates. The actual amount of oil devoted to fuel purposes varies continually with the condition of the production of crude petroleum. During the time of flush production, such as has existed in the Oklahoma fields during the past year due to the extraordinary production in the Cushing field, a great deal of crude petroleum is sold as fuel oil on account of the necessity of disposing of it when no better market is available. The use of such oil is not advisable for fuel purposes, not only because it contains valuable gasolene and kerosene, but these contents so lower the flashing point of the fuel oil as to make it open to the objections to gasolene stored in a confined space, as on a battleship, where the vapor is liable to produce explosions on contact with air.

"Until the last twelve months much of the production of California crude oil was sold for fuel purposes practically as it came from the well. Within the last year, however, the practice of topping off the valuable gasolene and kerosene in a comparatively small proportion of California oils has so increased that not more than 25 per cent. of the fuel oil of California is now crude oil. In States other than California and Oklahoma, and, to a slight extent, Texas, fuel oils consist chiefly of the least valuable distillates and some residuum. The distillates of such low value as to be sold for fuel oil are usually the products distilling off after kerosene, and those too heavy for burning in lamps and also too thin to be used as lubricating oils. Such oils generally have the name of gas oils, and are more valuable for use as gas oils than for fuel purposes, but the market for gas oils is easily over-supplied, and the surplus goes for fuel oil.

"The annual production of petroleum in the United States is about 266,000,000 barrels in round numbers, of which at least 100,000,000 barrels is consumed as fuel. This proportion will hold fairly well for the petroleum production of the world, that is, about 2-5 of the world's production may be considered 'fuel oil.' In regions such as the East Indies, the petroleum is to a large extent too valuable for use as fuel. This is offset by Mexico and Russia, where the use of residuum and even crude oil for fuel purposes is very general, and exceeds the average proportion."

DISTRIBUTING POINTS AND STORAGE AT SHORE STATIONS.

However great the incentive may be for vessel owners to adopt oil as fuel, there will be no universal use of it, as opposed to coal, until the supply is assured and distribution points, or fueling stations, are spread over the earth, where steamships may replenish their bunkers. In naval service the wonderful advantage which oil possesses of ability to "fuel" ships at sea by hauling a hose aboard from a tanker at safe towing distance, will be an added reason for the use of oil, and will facilitate the operation of the fleets in any waters. The merchant ship must, however, depend upon shore stations.

I am indebted to officials of the larger oil companies for the following instructive list of localities where fuel is available for ship use. In the

limited time, this could not be made complete. These stations are equipped with large storage tanks, frequently of a capacity of 55,000 barrels of oil each, with ample pumping capacity and pipe-line facilities leading from the tanks along the length of the docks or vessel berths on the water fronts.

The tankers from the oil fields tie up at the docks and discharge cargo to the tanks, either by means of their own pumps or, usually, the shore pumps. When vessels apply for fuel oil, the shore pumps put the oil into the bunkers on shipboard through the same pipes used for unloading the tankers. In many cases, also, the storage tanks are supplied by tank cars, or oil from the cars may be put directly on board the vessels. The tank cars, storage tanks and cargo holds of the tankers are provided with heating coils for heating the heavier oils.

Partial List of Oil Distributing Stations in the United States (Including Some Now Building).

Place.	Oil Company.	Storage capacity. Barrels of 42 gallons.
Aberdeen, Wash.	Standard Oil Co. of California	34,000
Alameda Point, Cal.	Associated Oil Co.	37,500
Aransas Pass, Tex.	The Texas Co.	55,000
Astoria, Ore.	Standard Oil Co. of California	10,000
Avon (Suisun Bay), Cal.	Associated Oil Co.	1,000,000
Baltimore, Md.	Interocean Oil Co.	220,000
Baltimore, Md.	Standard Oil Co. of N. Jersey	50,000
Baltimore, Md.	The Texas Company	55,000
Baton Rouge, La.	Standard Oil Co. of Louisiana	
Bayonne, N. J. (New York Harbor)	Standard Oil Co. of N. Jersey	300,000
Bayonne, N. J.	The Texas Co.	276,000
Bellingham, Wash.	Standard Oil Co. of California	8,500
Boston, Mass.	Mexican Petroleum Co.	200,000
Boston, Mass.	Standard Oil Co. of New York	50,000
Boston, Mass.	United States Navy	50,000
Carteret, N. J. (Near New York)	Interocean Oil Co.	100,000
Chester, Pa.	Interocean Oil Co.	120,000
Charleston, S. C.	Standard Oil Co. of N. Jersey	15,000
Charleston, S. C.	The Texas Co.	104,000
Charleston, S. C.	United States Navy	35,000
Cristobal, Panama	The Texas Co.	110,000
El Segundo, Cal.	Standard Oil Co. of California	100,000
Eureka, Cal.	Standard Oil Co. of California	35,000
Galveston, Texas	The Texas Co.	110,000
Gaviota, Cal. (Santa Barbara Channel)	Associated Oil Co.	120,000
Guantanamo Bay, Cuba	United States Navy	212,000
Honolulu, H. I.	Associated Oil Co.	102,000
Honolulu, H. I.	Standard Oil Co. of California	100,000
Jacksonville, Fla.	Standard Oil Co. of Kentucky	50,000
Jacksonville, Fla.	The Texas Co.	55,000
Ketchikan, Alaska	Standard Oil Co. of California	38,000
Key West, Fla.	Standard Oil Co. of Kentucky	50,000
Key West, Fla.	United States Navy	35,000
Linnton, Oregon (9 miles from Portland)	Associated Oil Co.	173,000
Marcus Hook, Del.	Sun Oil Co.	500,000
Mare Island, Cal.	United States Navy	100,000
Melville Station, R. I.	United States Navy	85,000

Place.	Oil Company.	Storage capacity. Barrels of 42 gallons.
Mobile, Ala.	The Texas Co.	25,000
Monterey, Cal.	Associated Oil Co.	340,000
Morgan City, La.	The Texas Co.	55,000
New Orleans, La.	Mexican Petroleum Co.	400,000
New Orleans, La.	The Texas Co.	124,000
New York, N. Y.	Mexican Petroleum Co.	500,000
New York, N. Y.	Standard Oil Co. of New York	100,000
Norfolk, Va.	The Texas Co.	138,000
Norfolk, Va.	United States Navy	185,000
Oakland, Cal.	Standard Oil Co. of California	10,000
Panama	Mexican Petroleum Co.	100,000
Pearl Harbor, Hawaii	United States Navy	235,000
Philadelphia, Pa.	The Texas Co.	334,000
Point Breeze, Pa. (Philadelphia)	Atlantic Refining Co.	500,000
Point Wells, Wash. (13 miles from Seattle)	Standard Oil Co. of California	200,000
Port Arthur, Texas	The Texas Co.	Practically unlimited
Port Chalmette, La.	Standard Oil Co. of Louisiana	
Port Costa, Cal. (Carquinez Strait)	Associated Oil Co.	480,000
Portland, Me.	Mexican Petroleum Co.	200,000
Portland, Me.	Standard Oil Co. of New York	30,000
Portland, Ore.	Standard Oil Co. of California	85,000
Port Townsend, Wash.	Standard Oil Co. of California	27,000
Providence, R. I.	Mexican Petroleum Co.	100,000
Providence, R. I.	Standard Oil Co. of New York	10,000
Providence, R. I.	The Texas Co.	253,000
Puget Sound, Wash.	United States Navy	100,000
Richmond, Cal.	Standard Oil Co. of California	200,000
Sacramento, Cal.	Associated Oil Co.	5,100
Sabine Pass, Texas	Sun Oil Co.	250,000
San Diego, Cal.	Standard Oil Co. of California	34,000
San Diego, Cal.	United States Navy	100,000
San Francisco, Cal.	Associated Oil Co.	97,800
San Francisco, Cal.	Standard Oil Co. of California	15,000
San Pedro (East), Cal.	Standard Oil Co. of California	35,000
Seattle, Wash.	Standard Oil Co. of California	90,000
Stockton, Cal.	Associated Oil Co.	5,200
Tacoma, Wash.	Standard Oil Co. of California	34,000
Tampa, Fla.	Standard Oil Co. of Kentucky	70,000

Fuel oil is obtainable from distributing stations of the Imperial Oil Company, Limited, at—

Fort William, Ontario.	Sarnia, Ontario.
Halifax, N. S.	Toronto, Ontario.
Montreal, Quebec.	Vancouver, B. C.
Prince Rupert, B. C.	Victoria, B. C.
Quebec, Quebec.	

Oil can also be obtained at many European and Asiatic ports and also in South America, but my efforts to secure a list of these stations have met with so little success, and the list is so incomplete, that I have concluded to omit it altogether.

OIL TANKERS.

Should further proof be necessary of the wide and ever increasing use of oil fuel and the possibilities of obtaining it at points remote from the oil fields, it may be found in the following list of oil tankers of the various nations. This list was prepared for me through the courtesy of Mr. W. A. Thompson, Manager of the Marine Department of the Texas Company, and is corrected to July 20, 1915. Other tank ships for carrying oil are now building. These modern vessels are equipped with the many devices which experience has demanded, for rapid filling and discharge through pipe lines, safe storage (many of them arranged to carry different grades of oil separately stored in the same cargo), swash plates, heating coils for heavy oils, provision for expansion of the oil due to temperature changes, and adequate ventilation of tanks, ingenious arrangements of valves and manifolds to simplify handling, measuring devices, etc., so that the carrying of oil in vessels is today decidedly a scientific business. Many of these tankers are still burning coal, but the rapid development of the fuel-oil industry is leading to the conversion of the tankers to oil burning.

Oil Tankers.

Flag.	Number of vessels.	Capacity—Barrels of 42 U. S. gallons.
American	158	6,190,135
British	177	8,888,631
German	22	1,263,214
Dutch	41	800,831
Norwegian	9	521,785
Mexican	4	121,190
Argentinian	3	42,619
Italian	3	67,500
Egyptian	1	
Cuban	2	32,976
French	7	270,547
Japanese	6	211,785
Greek	2	50,952
Danish	3	26,904
Roumanian	1	34,523
Portuguese	1	7,857
Spanish	1	5,357
Russian	2	42,143
Belgian	11	304,405

COMPARATIVE COST OF OIL FUEL.

The question whether or not it "pays" to use oil depends on many things. There may be reasons which make its adoption imperative at practically any cost—certain military advantages, for instance, such as smoke prevention, speed of vessels, etc.—but the merchant owner will be influenced by:

(1) Comparative cost with coal, wood or other fuel, delivered on board.

(2) Relative heat value of these fuels.

(3) Relative capacity and efficiency in steam production. This may result in running natural draft instead of forced draft, thus saving the cost of installing and operating blowers or in the installation of less boiler power.

(4) Expense of fitting up for oil, including suitable storage provision on the vessel.

(5) Saving in labor cost due to reduction in number of firemen, elimination of coal passers and the expense of removal of ashes.

(6) Increased life of the boilers and lower maintenance charges, both in the fire and engine rooms and hull of vessel.

(7) Increased bunker capacity and longer steaming radius, or otherwise, on fixed routes between fueling points, saving in dead weight and cargo space by carrying only sufficient oil for the trip.

(8) Time saved on voyage due to steadier steam pressure, and possibly time saved in fueling ship.

Coal may be figured at 42 cubic feet of bunker space per ton and oil at 36 to 40, according to the gravity. Thus, there is a saving of approximately 10 per cent. in space in carrying the same weight of oil, while pound for pound more than 40 per cent. more steam will be produced with oil—so that there is an increase of approximately 40 per cent. in steaming radius for the same weight of oil or nearly 55 per cent. for the weight of oil carried in the same bunker space, or, on the other hand, a saving of over 35 per cent. of bunker space or about 30 per cent. in weight for the same steaming radius.

It will be evident that while the cost of the fuel is important, it is not paramount, and must be considered only in connection with the whole general scheme.

Statements of comparative values of oil versus coal, therefore, while extremely common, are often misleading. We may, however, by making some reasonable assumptions, derive figures of more or less interest to the prospective user of oil. Assuming, therefore, that boiler capacity with oil is at least equal to that with coal; that boiler efficiency in everyday running will be in the ratio of 68 for coal and 75 with oil, and that the coal used for marine purposes will contain 14,400 B.t.u. per pound and that the oil will contain 18,600 B.t.u. per pound and weigh 7.88 pounds per gallon (18 degrees Baumé); that the coal is sold by the ton of 2,240 pounds and the oil by the U. S. gallon, or by the standard barrel of 42 gallons, we shall have the following equation when the cost of producing steam with oil equals the cost of producing the same steam with coal:

$$A \times 18{,}600 \times 7.88 \times 75 = \frac{B}{100} \times 14{,}400 \times 2240 \times 65$$

or

$$A = 1.907\ B$$

Where A = cost of coal in dollars per ton, and B = cost of oil in cents per gallon.

Thus, approximately, when the cost of coal in dollars per ton is double the cost of oil in cents per gallon, the fuel costs of producing steam will be equal. Mr. Walter M. McFarland is the first to point out this simple relationship in the cost of producing steam by coal and oil.

In round numbers, as a steam producer, a pound of oil is equal to a pound and a half of coal, or approximately one ton of coal is equal to four-and-a-half barrels of oil—or to quote another approximate but handy rule, one ton of coal equals 200 gallons of oil.

I am indebted to Mr. A. S. Hebble, Superintending Engineer of the Atlantic Coast Lines of the Southern Pacific R. R. Co. (Morgan Line), who has had a valuable experience in fitting out for oil fuel and operating vessels with Mexican crude oil, for the following comparison of results obtained, on the S. S. *El Norte*, in actual operation, first with coal and later with oil as fuel:

"S. S. *El Norte*, general dimensions: Length, 405 feet 0 inches; beam, 48 feet 0 inches; depth, 33 feet 9 inches; displacement, 7,600 tons.

"The vessel is fitted with a vertical, inverted, three-cylinder, three-crank, triple-expansion, surface-condensing engine with cylinders 32 inches — 52 inches — 84 inches x 54-inch stroke, and three double-ended Scotch marine boilers, 13 feet 10 inches in diameter by 21 feet 2 inches

FIG. 1.—OIL SPRING IN MEXICO.
(Courtesy Mexican Petroleum Co.)

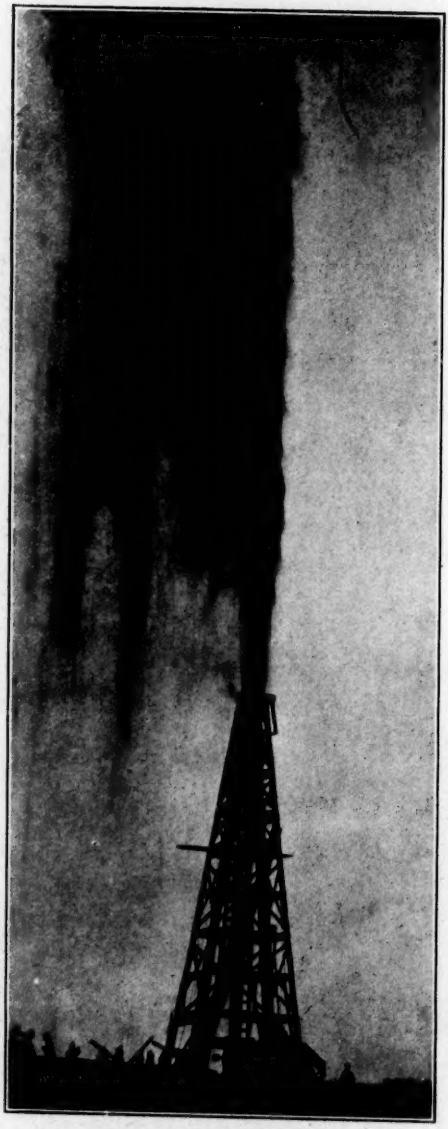


FIG. 2.—SPINDLE-TOP.
(Courtesy of Capt. Lucas.)

FIG. 3.—STORAGE AND DISTRIBUTING STATION, MEXICAN PETROLEUM CO., TAMPICO, MEXICO.

FIG. 4A.—STORAGE AND DISTRIBUTING STATION, TEXAS COMPANY, BAYONNE, N. J.

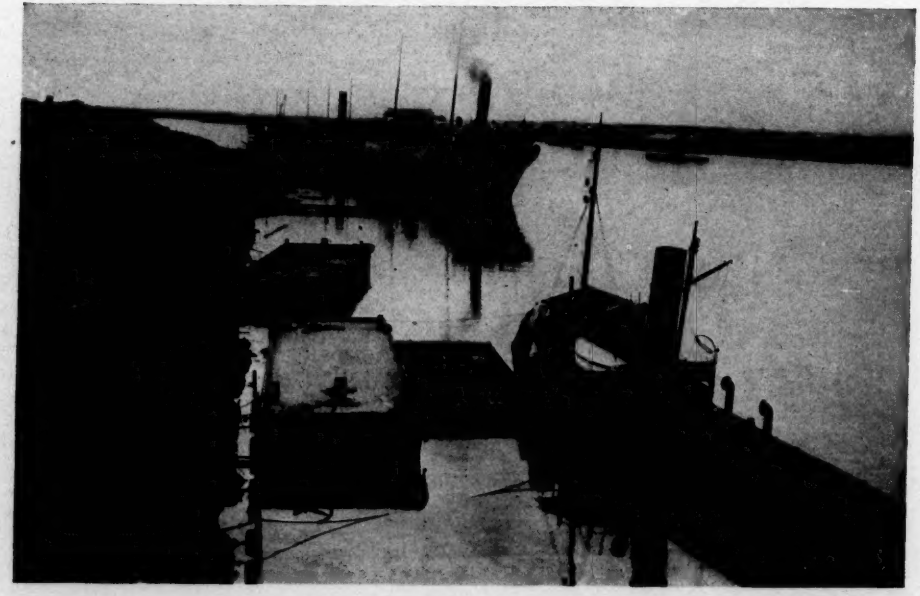


FIG. 4B.—OIL TANKERS LOADING AT TAMPICO.
(Courtesy Mexican Petroleum Co.)

WORLD'S TOTAL MARKETED PRODUCTION OF CRUDE PETROLEUM, 1857-1

	Roumania.	United States.	Italy.	Canada.	Russia.	Galicia.	Japan.	Germa
1857.....	1,977	.....	.....	.....	.....	.....	.....	.....
1858.....	3,560	.....	.....	.....	.....	.....	.....	.....
1859.....	4,349	2,000	.....	.....	.....	.....	.....	.....
1860.....	3,542	500,000	36	.....	.....	.....	.....	.....
1861.....	17,279	2,113,609	29	.....	.....	.....	.....	.....
1862.....	23,198	3,056,690	29	11,775	.....	.....	.....	.....
1863.....	27,943	2,611,309	58	82,814	40,816	.....	.....	.....
1864.....	33,013	2,116,109	72	90,000	64,586	.....	.....	.....
1865.....	39,017	2,497,700	2,265	110,000	66,542	.....	.....	.....
1866.....	42,534	3,597,700	992	175,000	83,052	.....	.....	.....
1867.....	50,838	3,347,300	791	190,000	119,917	.....	.....	.....
1868.....	55,369	3,646,117	367	200,000	88,327	.....	.....	.....
1869.....	58,533	4,215,000	144	220,000	202,308	.....	.....	.....
1870.....	83,765	5,260,745	86	250,000	204,618	.....	.....	.....
1871.....	90,030	5,205,234	273	269,397	165,129	.....	.....	.....
1872.....	91,251	6,293,194	331	308,100	184,391	.....	.....	.....
1873.....	104,036	9,893,786	467	365,052	474,379	.....	.....	.....
1874.....	103,177	10,926,945	604	168,807	583,751	149,837	.....	.....
1875.....	108,569	8,787,514	813	220,000	697,364	158,522	4,566	.....
1876.....	111,314	9,132,669	2,891	312,000	1,320,528	164,157	7,708	.....
1877.....	108,569	13,350,363	2,934	312,000	1,800,720	169,792	9,560	.....
1878.....	109,300	15,396,868	4,329	312,000	2,400,960	175,420	17,884	.....
1879.....	110,007	19,914,146	2,891	575,000	2,761,104	214,800	23,457	.....
1880.....	114,321	26,286,123	2,035	350,000	3,001,200	229,120	25,497	9,3
1881.....	121,511	27,661,238	1,237	275,000	3,601,441	286,400	16,751	29,2
1882.....	136,610	30,349,897	1,316	275,000	4,537,815	330,076	15,549	58,0
1883.....	139,486	23,449,633	1,618	250,000	6,002,401	365,160	20,473	26,7
1884.....	210,667	24,218,438	2,855	250,000	10,804,577	408,120	27,923	46,1
1885.....	193,411	21,858,785	1,941	250,000	13,924,596	465,400	29,237	41,3
1886.....	168,606	28,064,841	1,575	584,081	18,006,407	395,884	37,916	73,8
1887.....	181,907	28,283,483	1,496	525,655	18,367,781	343,882	28,645	74,2
1888.....	218,576	27,612,025	1,251	695,203	23,048,787	466,537	37,436	84,7
1889.....	297,666	35,163,513	1,273	704,690	24,609,407	515,268	52,811	68,2
1890.....	383,227	45,823,573	2,998	795,030	28,691,218	659,012	51,420	108,2
1891.....	488,201	54,292,655	8,305	755,298	34,573,181	630,730	52,917	108,9
1892.....	593,175	50,514,657	18,321	779,753	35,774,504	646,220	68,901	101,4
1893.....	535,655	48,431,066	19,069	798,406	40,456,519	692,669	106,384	99,3
1894.....	507,255	49,344,516	20,552	829,104	36,375,428	949,146	171,744	122,5
1895.....	575,200	52,892,276	25,843	726,138	46,140,174	1,452,999	141,310	121,2
1896.....	543,348	60,960,361	18,149	726,822	47,220,633	2,443,080	197,082	145,0
1897.....	570,886	60,475,516	18,892	709,857	54,399,568	2,226,368	218,559	165,7
1898.....	776,238	55,364,233	14,489	758,391	61,609,357	2,376,108	265,389	183,4
1899.....	1,425,777	57,070,850	16,121	808,570	65,954,968	2,313,047	536,079	192,2
1900.....	1,628,535	63,620,529	12,102	913,498	75,779,417	2,346,505	866,814	358,2
1901.....	1,678,320	69,389,194	16,150	756,679	85,168,556	3,251,544	1,110,790	319,6
1902.....	2,059,935	88,766,916	18,933	530,624	80,540,044	4,142,159	1,193,038	353,6
1903.....	2,763,117	100,461,337	17,876	486,697	75,591,256	5,284,475	1,209,371	445,8
1904.....	3,599,026	117,080,960	25,476	552,575	78,536,655	5,947,383	1,419,478	637,4
1905.....	4,420,987	134,717,580	44,027	634,095	54,960,270	5,765,317	1,472,804	560,9
1906.....	6,378,184	126,493,936	58,577	569,753	58,897,311	5,467,967	1,710,768	578,6
1907.....	8,118,207	166,095,335	59,875	788,872	61,850,734	8,455,841	2,001,838	756,6
1908.....	8,252,157	178,527,355	50,966	527,987	62,186,447	12,612,295	2,070,145	1,009,1
1909.....	9,327,278	183,170,874	42,388	420,755	65,970,350	14,932,799	1,889,563	1,018,8
1910.....	9,723,806	209,557,248	50,830	315,895	70,336,574	12,673,688	1,980,661	1,032,5
1911.....	11,107,450	220,449,391	74,709	291,096	66,183,691	10,519,270	1,658,903	1,017,0
1912.....	12,976,232	222,935,044	53,778	243,336	68,019,208	8,535,174	1,671,405	1,031,0
1913.....	13,554,768	248,446,230	47,256	228,080	62,834,356	7,818,130	1,942,009	995,7
1914.....	12,826,579	265,762,535	39,548	214,805	67,020,522	5,033,350	2,738,378	995,7
Total.....	117,982,474	3,335,457,140	802,229	23,493,610	1,622,233,845	131,873,601	27,051,158	12,965,8
Per cent	2.11	59.63	0.01	0.42	29.00	2.36	0.48	0.2

HUM, 1857-1914, BY YEARS AND BY COUNTRIES, IN BARRELS OF 42 GALLONS.

n.	Germany.	India.	Dutch East Indies.	Peru.	Mexico.	Trinidad.	Egypt.	Other countries.	Total.
.....	.....	.....	.....	.....	.....	.....	.....	.....	1,977
.....	.....	.....	.....	.....	.....	.....	.....	.....	3,560
.....	.....	.....	.....	.....	.....	.....	.....	.....	6,949
.....	.....	.....	.....	.....	.....	.....	.....	.....	506,578
.....	.....	.....	.....	.....	.....	.....	.....	.....	2,180,917
.....	.....	.....	.....	.....	.....	.....	.....	.....	3,091,692
.....	.....	.....	.....	.....	.....	.....	.....	.....	3,762,940
.....	.....	.....	.....	.....	.....	.....	.....	.....	2,303,780
.....	.....	.....	.....	.....	.....	.....	.....	.....	2,715,534
.....	.....	.....	.....	.....	.....	.....	.....	.....	3,899,378
.....	.....	.....	.....	.....	.....	.....	.....	.....	3,708,846
.....	.....	.....	.....	.....	.....	.....	.....	.....	3,990,180
.....	.....	.....	.....	.....	.....	.....	.....	.....	4,695,985
.....	.....	.....	.....	.....	.....	.....	.....	.....	5,799,214
.....	.....	.....	.....	.....	.....	.....	.....	.....	5,730,063
.....	.....	.....	.....	.....	.....	.....	.....	.....	6,877,267
.....	.....	.....	.....	.....	.....	.....	.....	.....	10,837,720
.....	.....	.....	.....	.....	.....	.....	.....	.....	11,933,121
566	.....	.....	.....	.....	.....	.....	.....	.....	9,977,348
708	.....	.....	.....	.....	.....	.....	.....	.....	11,051,267
560	.....	.....	.....	.....	.....	.....	.....	.....	15,753,938
384	.....	.....	.....	.....	.....	.....	.....	.....	18,416,761
457	.....	.....	.....	.....	.....	.....	.....	.....	23,601,405
497	9,310	.....	.....	.....	.....	.....	.....	.....	30,017,606
751	39,219	.....	.....	.....	.....	.....	.....	.....	31,992,797
549	58,025	.....	.....	.....	.....	.....	.....	.....	35,704,285
473	26,708	.....	.....	.....	.....	.....	.....	.....	30,255,479
928	46,161	.....	.....	.....	.....	.....	.....	.....	35,968,741
237	41,360	.....	.....	.....	.....	.....	.....	.....	36,764,730
916	73,864	.....	.....	.....	.....	.....	.....	.....	47,243,154
545	74,284	.....	.....	.....	.....	.....	.....	.....	47,807,082
436	84,782	.....	.....	.....	.....	.....	.....	.....	52,164,597
311	68,217	94,250	.....	.....	.....	.....	.....	.....	61,507,095
420	108,296	118,065	.....	.....	.....	.....	.....	.....	76,632,838
917	108,939	190,131	.....	.....	.....	.....	.....	.....	91,100,347
901	101,404	242,284	.....	.....	.....	.....	.....	.....	88,739,219
384	99,390	298,969	600,000	.....	.....	.....	.....	.....	92,038,127
744	122,564	327,218	688,170	.....	.....	.....	.....	.....	89,335,697
310	121,277	371,536	1,215,757	.....	.....	.....	.....	.....	103,662,510
082	145,061	429,979	1,427,132	47,536	.....	.....	.....	.....	114,159,183
559	165,745	545,704	2,551,649	70,831	.....	.....	.....	.....	121,948,575
389	183,427	542,110	2,964,035	70,905	.....	.....	.....	.....	124,924,682
079	192,282	940,971	1,795,961	89,166	.....	.....	.....	.....	121,143,743
314	358,397	1,078,364	2,353,355	274,800	.....	.....	.....	.....	149,122,116
790	313,630	1,430,716	4,013,710	274,800	.....	.....	.....	30,000	167,424,089
038	353,674	1,617,368	2,430,465	286,735	.....	.....	.....	26,000	161,965,876
371	445,818	2,510,259	5,770,056	278,092	.....	.....	.....	36,000	194,804,294
473	637,431	3,385,468	6,508,485	345,884	220,653	.....	.....	40,000	218,299,419
804	560,963	4,137,098	7,849,896	447,880	320,379	.....	.....	30,000	215,361,396
768	578,610	4,015,803	8,180,657	536,294	1,097,264	.....	.....	30,000	214,010,134
338	756,631	4,344,162	9,982,597	756,226	1,717,690	.....	.....	30,000	264,958,008
145	1,009,278	5,047,038	10,283,357	1,011,180	3,481,610	169	.....	30,000	285,089,984
563	1,018,837	6,676,517	11,041,852	1,316,118	2,488,742	57,143	.....	20,000	298,378,216
561	1,032,522	6,137,990	11,030,620	1,330,105	3,862,807	142,857	.....	20,000	327,615,608
903	1,017,045	6,451,303	12,172,949	1,368,274	14,051,643	285,307	9,150	45,000	345,685,061
405	1,031,050	7,116,672	10,845,624	1,751,143	16,558,215	436,805	205,905	105,000	352,494,591
009	995,764	7,930,149	11,966,857	2,133,261	25,902,439	503,616	94,635	270,000	384,667,550
378	995,764	8,000,000	12,705,208	1,917,802	21,188,427	643,583	777,038	620,000	400,483,489
158	12,965,569	73,979,919	138,278,392	14,806,972	90,359,869	2,069,430	1,086,738	1,322,000	5,593,263,936
	0.23	1.32	2.47	0.26	1.62	0.04	0.02	0.02	100.00

long, built for a working pressure of 180 pounds per square inch. Each boiler contains 6 corrugated furnaces, 42¾ inches inside diameter. Each furnace is fitted with one fuel-oil burner operated in connection with mechanical atomization system under natural draft. Each boiler contains 3,570 square feet of heating surface.

"The number of crew in the fireroom using coal was 12 firemen and 6 coal passers. The number of crew in the fireroom using oil is 6 firemen and 3 wipers.

"*Fuel Analyses.*—The following analyses show the average fuels on which this report is based:

Coal.		*Mexican Crude Oil.*	
Moisture	0.53%	Specific gravity at 70 deg. F.	0.9850
Ash	9.22%	Baumé gravity at 70 deg. F.	12.13
Sulphur	1.42%	Flash point, deg. F.	120.
Volatile com. matter	19.90%	Water	.60%
Fixed carbon	70.35%	B.t.u. per pound	18,191.0
B.t.u. per pound	14367.0		

"The average performance of the vessel for a period of 10 consecutive voyages, operating under the same general conditions in the same trade, using both coal and Mexican crude oil, is as follows:

Using Coal as Fuel.

Voyage No.	Total time at sea. Hrs.	Avg. Rev.	Total H.P.	Total coal. Sht. tons.	Lbs. of coal per H.P. per hr.
225	271.62	67.55	3660	747	1,502
226	276.13	64.50	3255	764	1.698
227	289.95	61.25	2860	690	1.666
228	271.93	66.05	3455	712	1.518
229	265.19	67.65	3675	769	1.576
230	300.30	62.60	3023	741	1.631
231	271.47	66.40	3504	755	1.586
232	275.87	67.45	3645	828	1.650
233	274.00	66.80	3558	808	1.660
234	282.45	66.90	3570	860	1.704
Average	277.89	65.72	3420.5	767.4	1.619

Using Mexican Crude Oil as Fuel.

Voyage No.	Total time at sea. Hrs.	Avg. Rev.	Total H.P.	Total oil. Gals.	Bbls. of oil. (42 gals.)	Lbs. of oil per H.P. per hr.
237	269.36	67.65	3675	148,400	3533.3	1.234
238	269.61	66.75	3550	123,900	2950.0	1.064
239	269.95	66.85	3560	118,000	2809.5	1.011
240	273.63	67.75	3685	129,819	3090.9	1.059
241	268.48	68.20	3750	138,578	3299.5	1.133
242	270.23	67.95	3715	142,173	3385.1	1.164
243	269.55	67.95	3715	126,946	3022.5	1.042
244	271.05	68.35	3775	147,781	3518.6	1.188
245	272.37	66.65	3535	122,410	2914.5	1.045
246	273.45	68.25	3760	142,000	3380.9	1.135
Average	270.76	67.64	3672	134,000.7	3190.5	1.108

Note.—Above calculations based on oil weighing 8.22 pounds per gallon.

"It will be noted from the above figures that the running time and average revolutions of the vessel are much more uniform when using oil than when using coal. This condition would be more particularly marked

but for the fact that the vessel is operated on schedule and not at the maximum speed. It is possible, however, with oil fuel to obtain maximum speed continuously, whereas with coal there is a perceptible falling off in speed due to adverse steaming conditions, cleaning fires and excessive temperature in the fireroom."

Mr. Hebble has also given me the following statement relative to cost of fitting out for oil, maintenance charges and the saving in ship's crews when operating with oil:

"The approximate cost of converting a coal-burning vessel to use oil, including pumps, piping, heaters, burners, etc., varies with the arrangement, horsepower and trade that the vessel is engaged in. Ordinarily, I should say that a coastwise vessel of 2,000 H.P. would cost between $30,000.00 and $40,000.00, and a similar vessel of 4,000 H.P. would cost between $40,000.00 and $50,000.00. This includes structural changes.

"The approximate cost of fitting a fuel-oil burning installation in a new vessel in the coastwise trade also depends on the conditions noted above, and I should say that for a 2,000 H.P. vessel the cost would be $20,000.00 to $25,000.00.

"The difference in crew as between an oil and coal-burning vessel of 1,500-2,000 H.P. would be about as follows:

"Required for coal—6 firemen, 6 coal passers—12 men.

"Required for oil—3 firemen, 3 wipers—5 men.

"The saving in crew in connection with an oil-burning installation increases rapidly with an increase in horsepower, *i. e.*, for a 4,000 H.P. vessel the crew would be:

"Required for coal—12 firemen, 6 coal passers—18 men.

"Required for oil—3 firemen, 3 wipers—6 men.

and for a 5,500 H.P. vessel:

"Required for coal—15 firemen, 9 coal passers—24 men.

"Required for oil—6 firemen, 4 wipers—10 men.

"A statement of saving in repairs and maintenance in connection with the use of fuel oil on shipboard in comparison with coal is rather indefinite, inasmuch as there are so many different types of vessels and conditions on which a saving might be based.

"The following is the estimated saving effected on a coastwise vessel of 5,000 gross tons and 3,800 I.H.P. per annum, exclusive of the fuel oil, and covers the following items:

"Wages and subsistence of crew.

"Maintenance of vessel's structure in bunkers and fireroom; including painting and renewal of floors, reverse bars, keelsons, tank tops, bulkheads, wooden ceiling, etc.

"Grate bars, liners and furnace fittings.

"Ash ejectors, ash ejector pipes and pumps and ash hoists.

"Fire doors, furnace fronts and ash pans.

"Protection plates.

"Fireroom floor and supporting angles.

"Fire shovels, fire tools and cost of dressing fire tools.

"Estimated saving, $9,000.00.

"All repairs to oil pumps, piping, etc., in connection with the fuel-oil installation, have been deducted from the total saving and the above amount is net."

Mr. Charles F. Bailey, Chief Engineer of the Newport News Shipbuilding and Dry Dock Company, to whom I am indebted for invaluable assistance in the preparation of this paper, gives the following figures relative to cost of fitting up vessels to burn oil:

"The cost of fitting up new vessels for fuel-oil burning, including furnishing and installing furnace fittings, burners, heaters, pumps, piping and oil meters for a 2,300 H.P. job, would be about $7,000 (weight 40,000 pounds); for a 4,000 H.P. job, about $10,000 (weight 65,000 pounds). The corresponding value of the coal-furnace fittings replaced by oil-fuel

fittings would amount to about 2,000 (weight 44,000 pounds) and $3,500 (weight 75,000 pounds) respectively. These figures include furnishing and installing the fuel-oil burning apparatus in place of coal-burning fittings and do not include the oiltight bunker work, which adds something to the cost of the vessel.

"The cost of fitting a new ship for oil burning is considerably less than converting an old job from coal burning to oil burning, on account of the great amount of structural work which is required to be rebuilt. The cost of the structural work incident to an oil-fuel installation on an old ship depends upon the design of the vessel and length of voyage, so that two ships of the same horsepower may differ materially in the cost of conversion. On a vessel of 3,800 H.P. a recent estimated cost of conversion amounted to about $70,000, while on another vessel of 2,300 H.P. the corresponding estimated cost of conversion was about $25,000."

The price of oil is, of course, a fluctuating figure, but it may be of interest to set down the following contract prices taken from the public opening of bids for oil supply for the U. S. Navy. I am told that these prices compare closely with those obtaining in commercial contracts.

Price Fuel Oil Per Barrel (42 Gallons) Fiscal Years 1914, 1915, 1916.

	Fiscal Year Ending June 30th.		
Delivered at	1914	1915	1916
Baltimore, Maryland	$2.08	$1.23	$1.12
Boston, Massachusetts	1.94	1.16	1.06
Charleston, South Carolina	2.09	1.23	1.07
New Orleans, Louisiana	1.69	.98	.84
New York, N. Y.	1.89	1.20	.84
Norfolk, Virginia	2.24	1.23	1.12
Philadelphia, Pennsylvania	1.89	1.20	1.04
Port Arthur, Texas	1.39	.78	.64
San Diego, California	.73	.85	.65
San Francisco, California	.73	.85	.60
San Pedro, California	.65	.80	.60
Seattle, Washington	.83	1.00	.735

While no general statement of cost can be used for obtaining more than an approximation for individual cases, it is hoped that what is given above may be of some assistance in showing the many advantages of oil over coal fuel and the probability of its saving money.

PHYSICAL PROPERTIES OF OIL.

The classification of oils according to their density is very commonly used to denote other characteristics. Thus, a "heavy" oil is usually expected to be viscous and sluggish with a high percentage of asphalt and comparatively low heat value, while a "light" oil is supposed to be very fluid at ordinary temperatures, very volatile and rich in the lighter hydrocarbons and high in heat value. While in general, these characteristics hold true enough to explain the prevalent association of ideas, there are so many exceptions and variations that it is essential to clearly specify the various properties of a particular oil in order to identify it. Density is *not* a measure of volatility, nor does weight necessarily determine viscosity. It may be noted also that the early theory that the density of oil was related to the depth of the oil well, has not been borne out in later exploration.

Analyses of Oil—Heat Value.—Fuel oil depends for its heat value almost entirely upon hydrogen and carbon, which although present in the liquid in many different combinations, still do not vary greatly in relative proportions when reduced to ultimate analysis. Thus, the hydrogen content of various crude oils varies usually from about 11 per cent. or 12

per cent to about 14 per cent. and the carbon from about 84 per cent. to about 87 per cent., slight amounts of oxygen, nitrogen and sulphur also being present.

The following table is reproduced from Holde's work on Examination of Hydrocarbon Oils:

Ultimate Analyses of Oils.

Source.	C.	H.	O.	S.	N.	Authority.
Pennsylvania	86.06	13.89	....	0.06	....	Engler.
Oil City, Pa.	85.80	14.04	....	....	....	Mabery.
Findley, Ohio	84.57	13.62	0.98	0.72	0.11	Mabery.
Lima, Ohio	85.00	13.80	....	0.60	0.68	Rakusin.
Beaumont, Texas	85.05	12.30	....	1.75	....	Richardson.
Ventura, Cal.	84.00	12.70	1.20	0.40	1.70	U. S. G.
Wasatch Range, Utah.	86.86	11.89	0.59	0.64	0.02	Mabery & Byerly.
Grossny .906	86.41	13.00	0.40	0.10	0.07	Charitschkoff.
Grossny .850	85.95	13.00	0.74	0.14	0.07	Charitschkoff.
Tcheleken .8736	86.40	12.44	0.377	....	....	Charitschkoff.
Campeni-Parjol	85.29	14.21	....	0.03	....	Edeleanu.
Bustenari (Prahowa)	86.30	13.32	....	0.18	....	Tanascu.

The ultimate analysis may serve for calculating the heat value of a fuel, but the use of the bomb calorimeter of the Mahler type is universally accepted as standard. In this instrument the latent heat of the vapor formed by the combustion of the hydrogen is included in the result—this proportion of the heat value is, however, not available for use in a furnace where the vapor passes away as superheated steam.

The heat value of fuel oil varies between about 16,000 and 20,000 B.t.u. per pound, 18,000 to 19,000 being the common values. The following table was prepared from the files of the Babcock & Wilcox Company:

Heat Value—Fuel Oil.

Source.	Specific gravity.	B.t.u. per pound.	Authority.
California, Coalinga Field	0.927	17,117	Bashore.
" Bakersfield Field	0.992	18,257	Wade.
" Kern River Field	0.950	18,845	Bashore.
" Los Angeles Field	0.977	18,280	Bashore.
" Monte Cristo Field	0.966	18,878	Bashore.
" Whittin Field	0.936	18,240	Wade.
Texas, Beaumont	0.924	19,060	U. S. Navy.
" "	0.903	19,349	Bashore.
" Sabine	0.937	18,662	Bashore.
Pennsylvania	0.886	19,210	Booth.
Mexico	0.921	18,840	Bashore.
"	0.981	17,551	Bashore.

In a paper published in the "Journal of the American Chemical Society," October, 1908, Sherman and Kropff call attention to the apparent relation of the calorific power of petroleum to its density. They present results of calorimeter tests on various oils running from gasolene having a specific gravity of 0.71 with a heat value of 21,120 B.t.u., to California crude oil having a specific gravity of 0.9644 with a heat value of 18,589 B.t.u. per pound, and for these oils they find that the following formula gives results remarkably close to those obtained with the calorimeter:

$$\text{B.t.u. per pound} = 18{,}650 + 40\ (\text{Baumé} - 10).$$

It will be observed that no oils under 15 Baumé were tested and the accuracy of this formula for such oils, particularly those containing con-

siderable sulphur, is doubtful. It is to be hoped that further experiment along these lines will be made.

Viscosity.—With the advent of the viscous crude oils of Mexico and the increased use of heavy distillates from other fields, coupled with the wider adoption of the mechanical atomizer, which will be described later in this paper, the degree of viscosity of the oil becomes a matter of considerable importance.

Viscosity may be described as the resistance to internal movement, or the internal friction of a liquid. It may be measured in various ways, as, for instance, observation of the ability of the liquid to oppose the movement of a body through it or immersed in it (Doolittle's disc, for example) or more commonly by noting the time required for a definite quantity of the liquid to pass through an orifice or short pipe under known conditions of temperature and head. This latter principle is used in the best known types of viscometers as developed by Saybolt, Redwood and Engler.

Mr. Geo. M. Saybolt, of the Standard Oil Company of New Jersey, constructed his instrument to meet the needs of his Company in the manufacture, primarily, of lubricants, where the measurement with absolutely accuracy of slight differences in viscosity was required in the work of the laboratories of the various factories. This viscometer is well adapted for testing fuel oils, and its accuracy and the ingenious overflow device for bringing the oil to the exact level required after its temperature has been determined, and immediately before the outlet is opened, are among the many features which have led to its extensive use among the oil companies of America. The instrument is now being widely introduced in other fields.

The following particulars apply to the standard Saybolt viscometer, which is illustrated in Fig. 5:

Inside diameter of oil tube	3.0	cm.
Depth, starting level to outlet jet	11.3	cm.
Length of outlet jet	1.3	cm.
Diameter of outlet jet	0.18	cm.
Charging quantity of oil	70	c.c.
Amount of oil discharged	60	c.c.

The time of outflow is taken in seconds by a stop watch, and the viscosity is reported in terms of the number of seconds required for 60 c.c. of the liquid to be discharged. The viscosity of water at 60 degrees F. is 30 on the Saybolt scale.

The oil tube is suspended in a bath of water, or for the higher temperatures, a suitable oil, and the later instruments are not only provided with the usual gas heating arrangement, but with a steam coil and an electric heater, any of these three methods of heating the bath being used at the option of the operator. The letters on the cut refer to parts, as follows:

A—oil tube thermometer; B—bath thermometer; C—electric heater; D—turntable cover; E—overflow cup; F—turntable handles; G—steam inlet or outlet; H—steam coil; J—oil tube; K—stirring paddles; L—bath vessel; M—electric heater receptacle; N—outlet cork stopper; P—gas burner; Q—strainer; R—receiving flask; S—base block; T—straining cup; U—pipette; V—tube cleaning plunger.

Sir Boverton Redwood, whose work on petroleum is world renowned, constructed a small vessel with an outlet "jet" made of agate. The instrument is standardized by use of rape oil, a viscous vegetable product having a specific gravity of 0.915. The agate jet is of such size and the instrument so proportioned that 50 c.c. of the rape oil at 60 degrees F. will flow out in 535 seconds. The oil to be tested is poured into the cup

to a certain level and carefully stirred and heated to the temperature at which it is desired to measure the viscosity. Fifty cubic centimeters are then allowed to flow out of the cup and the time is noted in seconds. The viscosity is expressed in terms of the viscosity of rape oil, *i. e.*, as a percentage of the time required for the outflow of the rape oil, and the result is further corrected for the density of the two oils. Fifty cubic centimeters of water at 60 degrees F. will take about 25½ seconds to flow out of the Redwood apparatus. The Redwood viscometer is much used in England.

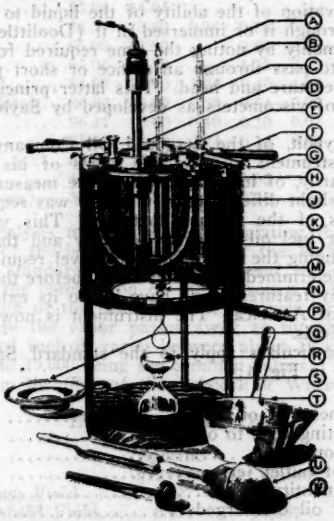


FIG. 5.—SAYBOLT VISCOMETER (TAGLIABUE STANDARD).

Dr. C. Engler, of Karlsruhe, uses a cup with a platinum tube at the bottom 20 m.m. in length, with a bore of 2.9 m.m. in diameter at the top, and 2.8 m.m. at the bottom. A volume of 200 c.c. of the oil to be tested is allowed to flow out and the time noted in seconds. The number of seconds required for 200 c.c. of water to flow out at a temperature of 20 degrees C. is then determined (this is 52 to 53 seconds in the standard instrument), and the viscosity of the oil is reported as the ratio of the time required for water to flow out to the time required for the liquid; *i. e.*, the viscosity is found by dividing the time required for the oil by the time required for the water. The viscosity of water is therefore unity on the Engler scale.

The Engler instrument is very widely used on the Continent of Europe, one reason for its popularity being the ease of calibrating with water and the fact that frequent calibrations eliminate errors due to slight wear or inaccuracy of the orifice.

Other types of instruments are also employed and they all include special and important devices for heating and stirring and accurately measuring the temperature of the oil.

Unfortunately the "viscosity" determined by each of these different instruments is on a scale of its own, no two are alike, and confusion frequently results from reports which carelessly omit mention of the kind

of viscometer used. Furthermore, the size and shape of the orifice and the proportions of the vessel affect the relative rate of flow of the various liquids, so that if rape oil were used by Engler and water by Redwood, two new viscosity scales would be introduced.

I have tried to secure tables giving the comparison of the standard Saybolt, Redwood and Engler viscometers, but while a few comparative figures of this kind are published, as for example, in the United States Navy Oil Specifications and also in Redwood's "Treatise on Petroleum," and elsewhere, I am told that no accurate table can be made for the reason that the relationship of the three scales differs with different characters of oil. This is only one of the added complications of the present practice of measuring viscosity, and in view of the increasing importance of viscosity tests of oil fuel, it seems to be high time for those versed in the art to devise some standard international method for determining viscosity and a standard scale for reporting the results.

One of the methods suggested is that wherein the coefficient of absolute viscosity is found by forcing the liquid at known pressure and temperature through a capillary tube. This was worked out by Poiseuille, whose formula is as follows:

$$AV = \frac{\pi p r^4}{8vl} t,$$

Where A V = the absolute viscosity in dynes, or the units required to move a layer of the liquid of one square centimeter area over another layer of the liquid with a velocity of one centimeter per second.

p = pressure in grams per square centimeter.
r = radius of the capillary tube in fractions of centimeters.
l = length of tube in centimeters.
v = volume of liquid passed through the tube in cubic centimeters.
t = time in seconds.

The absolute viscosity of water at 0 degree C. = 0.018086. If this were taken as unity and the absolute viscosity of other liquids were expressed in these units, the result might be called "specific viscosity." This method is also one which is urged as an international standard. The Engler Scale, while using as a basis the viscosity of water, does not give true "specific viscosity," for the reason that a liquid flowing through an orifice is affected by other things, *e. g.*, the acceleration due to gravity, etc. A method, however, of converting to specific viscosity the viscosity measured in degrees Engler (using the Engler Standard Instrument), has been worked out by Ubbelohde as follows:

$$SV = S\left(4.072\,E - \frac{3.514}{E}\right).$$

Where S V = the specific viscosity of the liquid referred to water at 0 degree C.

S = the specific gravity of the liquid at the temperature of the test.
E = degrees Engler (Standard Instrument).

With values of Engler degrees greater than 10 (and these are the viscosities which interest us particularly), the fractional part of the formula is comparatively small and may be neglected, and Ubbelohde's formula becomes:

$$SV = S\,(4.072E).$$

Obviously it would be entirely possible to work out formulae for each of the various fixed types of viscometers. Why then should not "specific viscosity" in the sense used above, be adopted as standard? Would it not

be equally as satisfactory as the use of "specific heat" and "specific gravity?"

This subject is treated fully in Holde's work on "Examination of Hydrocarbon Oils"—translated by Mueller, and published by John Wiley & Sons, New York, 1915. Through the courtesy of the publishers, I reproduce herewith a diagram for the graphical determination of specific viscosity when the Engler degrees and specific gravity of the oil are known. Figure 6.

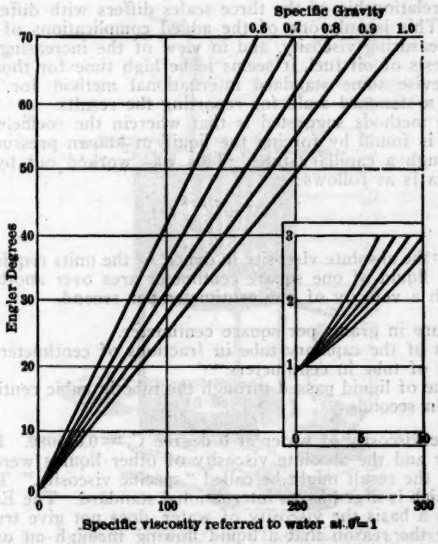


FIG. 6.—CURVES FOR CONVERTING DEGREES ENGLER TO SPECIFIC VISCOSITY.
(Courtesy John Wiley & Sons.)

I have discussed this matter at some length, as it seems to me that the growing importance of viscosity in handling fuel oils demands some sort of standard practice and general agreement in place of the present numerous and diverse methods, and the confusion they lead to.

In atomizing oil by means of the mechanical atomizer or pressure burner, it is important to know to what degree the viscosity must be reduced and to what temperature the oil must be heated to accomplish this result. Also, the most viscous oils cannot be pumped without heating. The whole problem, therefore, of handling heavy oil—in fact any oil—really hinges on the matter of viscosity.

In a valuable paper on oil burning, by Lieutenant Commander John J. Hyland, U. S. N., published in the "JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS," May, 1914, the results of some of the experiments conducted by him at the U. S. Fuel-Oil Testing Plant at the Philadelphia Navy Yard, are reported. The viscosity of a large number of representative fuel oils at various temperatures was determined for Commander Hyland by Mr. C. A. Cratty, Chemist at the Yard, and these were plotted by Hyland and published in his paper. I have reproduced the curves on

TEMPERATURE -VISCOSITY D

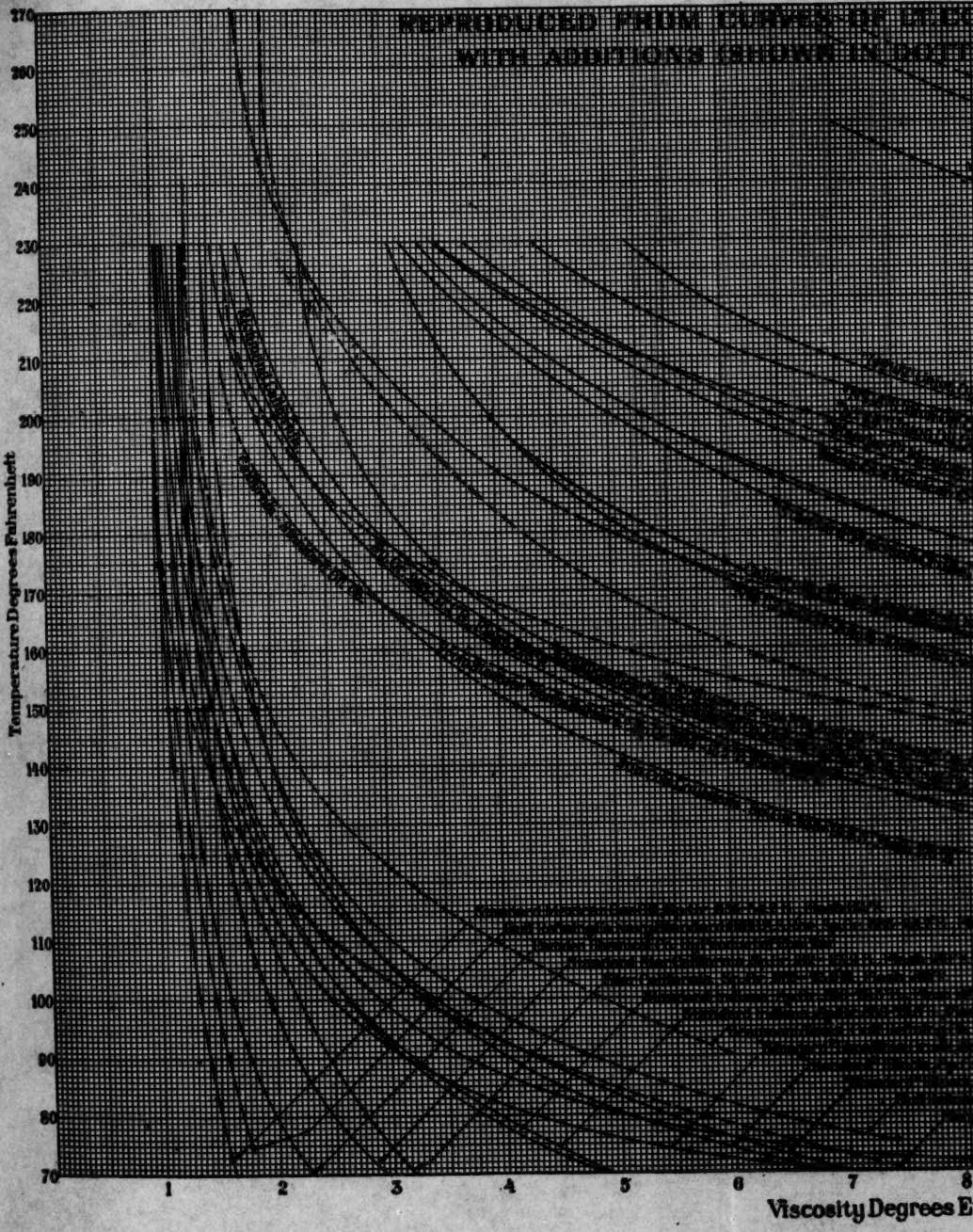
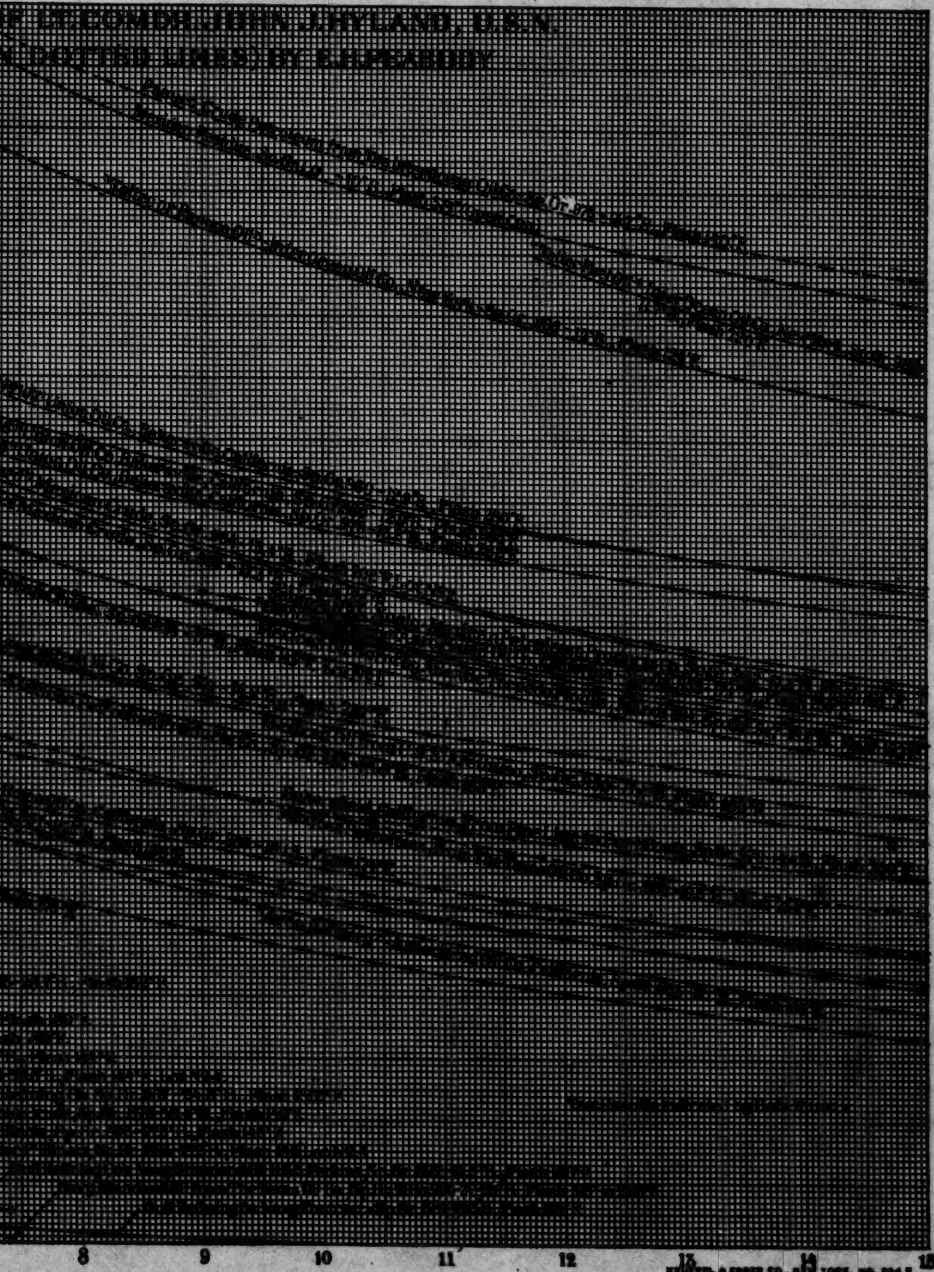


FIG. 7.—TEMPERATURE–VISC

TY DIAGRAM OF FUEL OILS



E–VISCOSITY DIAGRAM.

a different scale, omitting, for the sake of clearness, the results at the lower temperatures. In addition to all of Hyland's curves I have added a few curves for oils used in some of our experiments, the viscosity tests being made by Mr. E. G. Bashore, Chemist for The Babcock & Wilcox Company.

Commander Hyland found that in order to get full capacity from a 6-inch by 6½-inch by 12-inch Blake pump, the viscosity of the oil had to be reduced to 375 degrees Engler. He states, also, that in order to atomize the oil sufficiently to burn without smoke, using the mechanical atomizer, the viscosity had to be reduced to 8 degrees Engler, and that further heating did not improve the evaporation. In our experiments we have not found it necessary to go quite to the 8-degree mark, but have found 10 degrees to 12 degrees Engler sufficiently low in viscosity. This is, however, a substantial confirmation of Hyland's figures.

An interesting point in this connection is that apparently the oils naturally the least viscous required reduction of the viscosity to the lower point. Thus, while a light oil required sufficient heating to reduce the viscosity to 8 degrees or 10 degrees Engler, the heavy oils could be handled with equal satisfaction by reducing the viscosity to only 12 degrees or 15 degrees Engler. However, all these heavy oils required heating above 212 degrees F. to get the viscosity down to the 15-degree mark; and, as there was some water present in small amounts in these oils, it is rather tempting to speculate on the effect which might have been produced by the moisture, in flashing into steam at the burner tip.

Flash Point.—The "flash point" of oil is the temperature at which inflammable gas or vapor is given off. It is determined simply by heating the oil and as the temperature rises testing it with a spark or flame until the vapor is distilled off and ignites and the "flash" is noticed. The oil must be carefully stirred in order to get a uniform temperature and measure the same correctly, and it is obvious that conditions of the test may introduce wide differences in results. Thus, merely by closing in the top of the vessel in which the test is made, the "flash" will be detected sooner and at a lower temperature than if the vessel is entirely open. This explains the use of the "closed-cup" as opposed to the "open-cup" apparatus. The former is the more accurate, and instruments devised by Pensky and Marten and by Abel are recognized as standard for fuel oil.

The "burning point" is the temperature at which sufficient vapor is given off to remain ignited, and as a free supply of oxygen is required, this test is made with the open cup.

Heating Above Flash Point.—It will be apparent upon inspection of Hyland's curves that certain oils require heating above the flash point—not for any supposed advantage of allowing the oil to flash into gas, but merely for the purpose of reducing the viscosity to a point where the mechanical atomizer will handle the oil successfully. This is undoubtedly a condition which introduces an element of danger in the use of oil on shipboard. Some slight unnoticed leak in the piping system or at a burner may allow gas or vapor to collect in the fireroom, which on being mixed with a certain proportion of air and exposed to a naked light may produce a more or less disastrous explosion.

This element of possible danger is often set aside as of trifling consequence, or not considered at all, or no leak in the piping having occurred, it is contended that none ever will.

Further, it is claimed by some authorities that the vapor which would be liberated in this way is exceedingly small—not enough in fact to introduce any considerable danger. Not being able to learn of any actual tests which had ever been made on viscous crude oil to determine the amount of oil which would be distilled off in the process of heating sufficiently high to reduce the viscosity to 8 degrees Engler, I took the matter up with the U. S. Bureau of Mines at Washington. A sample of

Panuco (Mexican) crude from the Bayonne station of The Texas Company was furnished us for the test, through the courtesy of Mr. W. A. Thompson. Unfortunately the results have not been received in time to be presented in this paper.

It must be understood that only a part of the oil is volatilized when a temperature above the flash point is reached; that is, there is no possibility of the whole body of the oil flashing into vapor, but even if a portion is given off, the amount of this vapor may be constantly added to by new oil approaching the hidden leak.

In this connection, the oil specifications of the United States Navy are of special interest—as it will be noted that a "safe" oil is insisted upon.

"*Oil Specifications—U. S. Navy—1915.*

"(a) Fuel oil shall be a hydrocarbon oil of best quality, free from grit, acid, and of fibrous and other foreign matter likely to clog or injure the burners or valves.

"(b) The unit of quantity to be the barrel of 42 gallons of 231 cubic inches at a standard temperature of 60 degrees F. For every variation of temperature of 10 degrees F. from standard, 0.4 of 1 per cent. shall be added or deducted from the measured or gaged quantity for correction.

"(c) Flash point never under 150 degrees F. as a minimum (Abel or Pensky-Marten's closed cup), or 175 degrees F. (Tagliabue open cup), and not lower than the temperature at which the oil has a viscosity of 8 degrees Engler (water = 1 Engler). (Example: If an oil has a viscosity of 8 Engler when heated to 186 degrees F., then 186 degrees is the minimum flash point at which this oil will be accepted.)

"(d) Viscosity at 100 degrees F. not greater than 200 Engler.

"(e) Water and sediment not over 1 per cent. If in excess of 1 per cent., the excess to be subtracted from the volume; or the oil may be rejected.

"NOTE.—If an Engler viscosimeter is not available, the Saybolt standard universal viscosimeter may be used, and 280 seconds Saybolt will be considered equivalent to 8 Engler, and 7,000 seconds Saybolt will be considered equivalent to 200 Engler. Water at 60 degrees F. = 30 seconds Saybolt.

"(f) Water and sediment will be taken by the distillation method. When oil in small lots is consigned to naval vessels or to navy yards, the centrifuge test will be used in order to obviate delay. In this test 50 c.c. of oil and an equal quantity of the best commercial benzol, 50 per cent. white, will be used, and the mixture heated to 100 degrees F."

Any oil can, of course, be made "safe" in this respect by distillation, if not by merely "topping" or "blowing" heated air through the oil to drive off the light vapors. Will it pay to do this? Will oil users be content to take the crude oil as they get it, regardless of how much above the flash point it has to be heated? Will the oil companies continue to put this oil on the market? How about insurance? These questions will be answered in the course of time, but at any rate the point ought to be fully understood and the possible danger appreciated by oil users. I wish to take this opportunity to point out that the flash point alone is not enough, but rather the flash point must be considered in connection with viscosity.

Density of Oil—Specific Gravity.—The Baumé hydrometer scale for liquids lighter than water has obtained a strong hold in the oil industry, and for light oils this practice is justified by the ease with which the "gravity" may be determined—namely, by the simple reading of the scale on the stem of the hydrometer immersed in the liquid. But for heavy viscous oil, the very nature of the oil makes the process a slow one and liable also to considerable error. It is believed by some that for these oils it is much better to determine the weight of a known volume of the oil (as in the specific gravity bottle), and report the density in terms of the density of water at 60 degrees F., *i. e.*, as specific gravity.

On the other hand, there are advocates of the method of heating the viscous oils sufficiently to make the use of the Baumé hydrometer feasible—making the necessary corrections for temperature.

The reluctance to abandon the Baumé scale and give the actual specific gravity is due probably to our inherent dislike to continually report results in fractional units; but as the oils in general use become heavier and the hydrometer itself becomes impracticable, it is probable that the Baumé scale will be less commonly used. In fact, already oils of 10 degrees Baumé (the specific gravity of water) are used as fuel, and should the limit go a bit further, we should be confronted with the alternative either of reporting the density in terms of specific gravity, or of bringing into use the other Baumé scale, for liquids heavier than water—a most undesirable complication.

The United States Bureau of Standards has adopted the following formula for converting readings on the Baumé scale lighter than water, to terms of specific gravity:

$$\text{Specific gravity at } 60^\circ \text{ F.} = \frac{140}{130 + \text{Baumé.}}$$

I am informed that many Baumé hydrometers on the market are constructed with scales on the modulus of

$$\text{S.G.} = \frac{141.5}{131.5 + \text{Baumé.}}$$

For fuel oils, the difference is negligible ; but of course if specific gravity is to be figured from the reading of a hydrometer, the formula should fit the instrument.

The following table is given for reference:

Baumé Liquids Lighter Than Water.	Specific Gravity 60° F.	Weight in Pounds—60 Degrees F. Per U. S. Gal.	Per Cu. Ft.	Per Barrel. 42 Gals.
10	1.000	8.337	62.368	350.2
11	0.993	8.280	61.93	347.7
12	0.986	8.222	61.50	345.3
13	0.980	8.171	61.12	343.2
14	0.973	8.112	60.68	340.7
15	0.966	8.054	60.25	338.3
16	0.959	7.996	59.81	335.8
17	0.952	7.937	59.37	333.4
18	0.946	7.887	59.00	331.3
19	0.940	7.837	58.63	329.2
20	0.933	7.779	58.19	326.7
21	0.927	7.729	57.82	324.6
22	0.921	7.679	57.44	322.5
23	0.915	7.629	57.07	320.4
24	0.909	7.579	56.69	318.3
25	0.903	7.529	56.32	316.2
26	0.897	7.479	55.94	314.1
27	0.892	7.437	55.63	312.4
28	0.886	7.387	55.26	310.3
29	0.881	7.345	54.95	308.5
30	0.875	7.295	54.57	306.4
35	0.848	7.070	52.89	296.9
40	0.823	6.862	51.33	288.2

Specific Heat of Oil.—The specific heat of oil varies with its composition. It will be greater the richer the oil is in hydrogen, and lower in proportion to a greater carbon content.

The following figures are reproduced from Holde's Work on Examination of Hydrocarbon Oils, referred to above:

Crude Oils from—	S. G.	S.H.
Japan	.862	.453
Pennsylvania	.810	.500
Russia	.908	.435
California	.960	.398
Bustenari	.842	.462

Coefficient of Expansion of Oil.—It may be considered that at ordinary temperature crude petroleum expands under the influence of heat approximately five ten-thousandths (0.0005) of its volume for each degree Fahrenheit (0.0009 per degree C.). This coefficient decreases for the heavier oils being a function of the specific gravity.*

CONVERSION OF VESSELS FOR USE WITH COAL OR OIL.

While the U. S. Navy has definitely adopted oil fuel for all classes of service and the later vessels are constructed without provision for coal bunkers, it may appear of advantage to the mercantile vessel owner to be ready to use either fuel. This can be easily accomplished if means are provided for carrying coal fuel.

The change of the boilers consists merely of removal of the burners and oil piping, air-controlling mechanism and special brickwork that may have been used, and substitution of a few necessaries, such as grate bars and fire doors. In fact, where steam-atomizing burners are used, the grate bars and bearers are usually retained while burning oil, and merely covered with a protecting layer of fire brick.

The changes in the bunkers also are simple, if proper precautions are taken beforehand.

Mr. George Simpson, the well known naval architect, gives the following rules for arranging the bunkers for alternate use with either fuel:

Specification for Coal or Fuel-Oil Bunker.

General Description—"The cross bunker to be arranged adjacent to the fireroom and to consist of two thwartship oiltight bulkheads of a predetermined capacity. There shall be a centerline oiltight bulkhead dividing the cross bunker into port and starboard compartments, and in addition there shall be partial swash bulkheads extending throughout the upper half of the bunker.

"The hatchway shall consist of a coaming 24 inches in height plated over the top and arranged with two oil hatches.

Oiltight Bulkheads.—"The oiltight bulkheads must be suitably stiffened with vertical stiffeners and webs, as well as horizontal girders, the scantlings and arrangement being as required by Lloyd's Rules for oiltight work. The centerline bulkhead should extend from inner bottom to coaling hatch with plating and stiffeners to Lloyd's requirements.

*Subsequent to the presentation of this paper, a valuable treatise reporting the investigations of the Bureau of Mines on the coefficient of expansion of California crude oils and distillates was presented at the first annual meeting of the American Petroleum Society at San Francisco by Mr. A. S. Crossfield. The conclusions arrived at are as follows:

"1. The value of the coefficient now used in California practice approximates 0.0009 per 1 degree C. (0.0005 per 1 degree F.). From the results of this investigation it is apparent that this value is considerably too high, and that the correct value more nearly approaches 0.00072 per 1 degree C. (0.0004 per 1 degree F.).

"2. The value of the coefficient for crude oils and distillates, within the ranges of temperature used, is a straight-line function of the temperature and increases with an increase in temperature.

"3. The value of the coefficient for crude oils, within the ranges of specific gravity used, is a straight-line function of the specific gravity and decreases with an increase in specific gravity. The value for distillates deviates somewhat from a straight line."

Hatchway.—"A steel cover on top of the 24-inch coaming forming the hatchway shall be arranged with hinges and drop bolts to enable the whole of cover to be readily opened up for coaling purposes, and when carrying oil this cover will be arranged with a lamp-wick gasket and the cover screwed down and made oiltight. In addition there shall be two small oil hatches on the main hatchway cover arranged so as to be readily opened and fitted with peep holes and ventilators.

Coal Doors.—"The stokehold bulkhead to be arranged with coal doors of the usual dimensions, the frames of which shall be secured with bolts and nuts so as to be readily removable when changing over to oil, and a steel plate cover substituted and set up on a lamp-wick gasket, or alternatively, the plate may be riveted in place and caulked.

Fuel-Oil System.—"The fuel-oil system shall consist of a high and a low suction in each tank led to Warren or other suitable oil-fuel pumps with the usual arrangement of heaters, duplex strainers, meters and thermometers, the whole system being cross-connected and interchangeable so that the breakdown of one pump need not put that particular unit of the system out of commission, but can be connected up with the other pump and these pumps so cross-connected that each can handle its own or opposite system.

Finally.—"Generally there is no practical difficulty in arranging a cross bunker for the stowage of either coal or fuel oil provided the hatchway is made large enough and arranged with a steel cover. Care should be observed in arranging the wing swash plates that they shall only extend for the upper part, thus permitting the coal to gravitate freely to the bunker doors.

"With a system such as has been outlined in the foregoing, a change over from one fuel to the other can be made in a few hours."

PRECAUTIONS AGAINST DANGER.

The time is long past when the use of oil fuel on shipboard is opposed on account of insurmountable danger. Oil has the distinct advantage over coal that it is not subject to spontaneous combustion, and many fires which have occurred in ships' bunkers at sea would not have been possible with oil. Certain precautions, however, must be taken—such as suitable arrangements of vent pipes, protection of bunker bulkheads, if exposed to heat, and particularly the use of an oil with a reasonably high flash point. The United States Navy, in cooperation with the Bureau of Mines, has investigated the matter of possible explosion of gases in storage tanks, and it was found that no inflammable gases were formed in any amount in the storage tanks or bunkers until the oil was heated to the flash point, *i. e.*, that the representative oils tested contained no dissolved gas or vapor sufficient to form an explosive mixture at temperatures below the flash point. The largest percentage of vapor in the atmosphere of fuel-oil tanks of various battleships tested was 0.04 per cent., whereas, about 0.9 per cent. is required to form an explosive mixture. It was also found that any oil in the bunker tank had to be heated to within 60 degrees F. of the flash point before even a faint "glow" or partial burning was obtained on introducing a naked flame in the tank.

These important investigations show that oil is perfectly safe on board ship so long as the flash point is sufficiently above the temperature to which the oil may be exposed.

On the other hand, while careful attention to ventilation of the tanks and leading the vent pipes well away from all possible chance of exposure to flame may result in immunity from trouble, the conclusion is forced upon us that the use of heavy oils which have to be heated in the tanks and bunkers may lead to very serious consequences through the necessity of installing heating coils in the tanks, and the possibility that the oil may become heated to the flash point through carelessness. This is a different matter entirely from heating the oil for use at the burners. The

oil may be pumped at temperatures which are perfectly safe—but what assurance is there that it may not be overheated by careless handling of the heating coils in the tanks. It seems to me that this matter has been relegated to the condition where safety against explosion depends too nearly on vigilance alone. The steam smothering pipes which are usually installed provide fairly effective means for extinguishing possible fires in the tanks, and the U. S. Board of Supervising Inspectors of Steam Vessels recommend that valves should be fitted on all suction pipes on the *inside* of the tank, with stems extending to the deck above the tank; they also recommend similar extensions to the valve rod on the steam connection to the oil pump, so that the latter may be shut down from outside the fireroom. The only other precautions are the fitting of lead pans underneath Scotch boilers to catch any drip of oil due to leakage, and the provision of a supply of sand in the boiler room itself for the purpose of extinguishing incipient fires. These precautions may prevent fires, but not explosions. Automatic devices for closing the valves on the steam-heating coils in the tank when the oil reaches a predetermined temperature might be advisable, but even then "eternal vigilance is the price of safety."

I have already referred to the possible danger due to heating oil above the flash point, and there is always the potential danger that some careless or ignorant fireman may try to light a burner which has been atomizing oil and injecting it in the form of spray into the furnace for some time previous to lighting. In this case it is quite possible that an explosion in the boiler furnace may occur, and for this reason some engineers object to having dampers installed in the uptakes, or, if installed, they insist on having them locked in the open position. This by the way will not prevent an explosion under the above conditions. Personally, I am a strong advocate of the use of the damper for air regulation, and I believe that the added danger due to having the damper closed is of little account. If the simple precaution is taken of always having a lighted torch under the burner before turning on the oil, no possible danger of explosion in the furnace can exist.

Several methods of extinguishing fires at sea by the use of carbonic acid gas are being developed, such as the Gronwald System, advanced by the British Ships Fire Syndicate of Cardiff, Wales, which consists of the installation of tanks at suitable points containing liquid carbonic acid gas under high pressure. These tanks are piped to various parts of the ship, where possible danger from fire might exist, and the gas is admitted to these points in emergency, thus completely blanketing the fire and shutting off the supply of oxygen.

Another system which has been very effective in extinguishing fires in oil tanks ashore is that known as the Erwin System, manufactured by Treadwell and Company of New York. A mixture of bicarbonate of soda and soap bark is carried in one tank, and sulphuric acid is carried in another, nearby, and these may be mixed automatically or at will, resulting in the liberation of a large mass of foam impregnated with carbonic acid gas.

Carbon tetrachloride has been used for extinguishing fires; this is best known in commercial form in the portable tanks of Pyrene.

It occurs to the layman that quite as much danger may result from the installation of tanks of this highly asphyxiating material on board ship as would be caused by fire, but undoubtedly experience will show the efficiency as well as the necessity of these various methods of extinguishing fires.

STORAGE ON BOARD.

By no means the least of the advantages of oil over coal is its adaptability for storage in almost any part of the vessel—in the ordinary bunker space, or in tanks remote from the fireroom, or in double bot-

toms. Special precautions must be taken to prevent and to detect leakage from the tanks. Special riveting is employed and frequently coffer-dams are built around the oil tanks. Coffer-dams around the oil tanks are recommended but not insisted upon by any of the Classification Societies, except where "low flash point" oils are allowed, *i. e.*, oils having a flash point below 150 degrees F. In other words, while oil is easily handled, the feasibility of its use on shipboard depends primarily on the ability to keep it where it is stowed until it is pumped to the burners. In deep tanks, swash plates are installed to prevent undue motion of the liquid in the tanks when partly filled. Expansion trunks are provided to allow for increase in volume due to heating; vent pipes are carried above the decks to carry away vapor given off by the oil. These are fitted with goose-necks at the top covered with wire gauze, and sometimes in destroyers or vessels of low freeboard the vents have special automatic valves at the end instead of the simple goose-neck, for discharging vapor and at the same time preventing water from entering the tanks.

Sounding pipes for measuring depth of oil in the tanks are provided. These should be of ample size, anything less than 2½ inches being unreliable for deep tanks in which viscous Mexican oil is carried. It is advisable to drill small holes in these pipes to give free access to the oil at all depths, as it is possible for some difference in density to exist at the various levels, if the oil has been standing for some time. Heavier oil at the bottom would give an erroneous reading if the sounding pipe were open at the bottom end only.

In closed tanks the combined area of the vents and sounding pipes must be sufficient to provide an adequate overflow in the case of too rapid filling, which might put an undue pressure on the tank. For this reason, when tanks in the lower part of the vessel, such as the double bottoms, are used for oil, it is advisable to fill through a system of relay tanks which eliminates the danger of a large "head" of oil exerting a heavy pressure on the storage tanks. Mr. Bailey has furnished me a diagram of the system being installed on the Battleships *Pennsylvania* and *Mississippi*, which is here reproduced with the permission of the Navy Department. See Figure 8.

Two 6-inch pipes with valves are located on each side of the ship, connecting with one 8-inch filling pipe on each side, which runs to the relay tank. The latter is fitted with a removable cover and a large (10-inch) overflow closed by a relief valve with a very light spring. Filling pipes lead from the relay tank to the storage tanks, and it is evident that the greatest pressure which can be put on the latter is that due to the head from the relay tank, which can be reduced to a small amount by suitably locating such tank. The vent pipes from the storage tanks lead into the relay tank, which is fitted with a common vent pipe leading to the atmosphere and covered at the end with wire gauze. The supply pipes to the relay tanks are fitted with quick-closing valves and the relay tank is equipped with a gage glass to mark the level of the oil. Also an annunciator at the relay tank, operating from the "pneumercators" fitted in the storage tanks, gives warning when the latter are 95 per cent. full. On the relay tank which is used only in filling and not for permanent storage, the fitting of a gage glass is no doubt justified, but the use of fittings of any kind on the outside of the tanks below the oil level is in general very bad practice, and should be avoided where possible. Notwithstanding reports of trouble due to loss of vacuum, I question even if pump suctions could not be fitted through the top of the tank, thus avoiding all possible danger of oil leaking, or breaking loose in case of accident.

Floating suctions, in storage tanks, for taking the oil from a point near the surface are no longer considered necessary, the usual practice being to use a high and low suction, *i. e.*, two pipes either separate or connected through a manifold, one taking the oil from a level 12 or 18

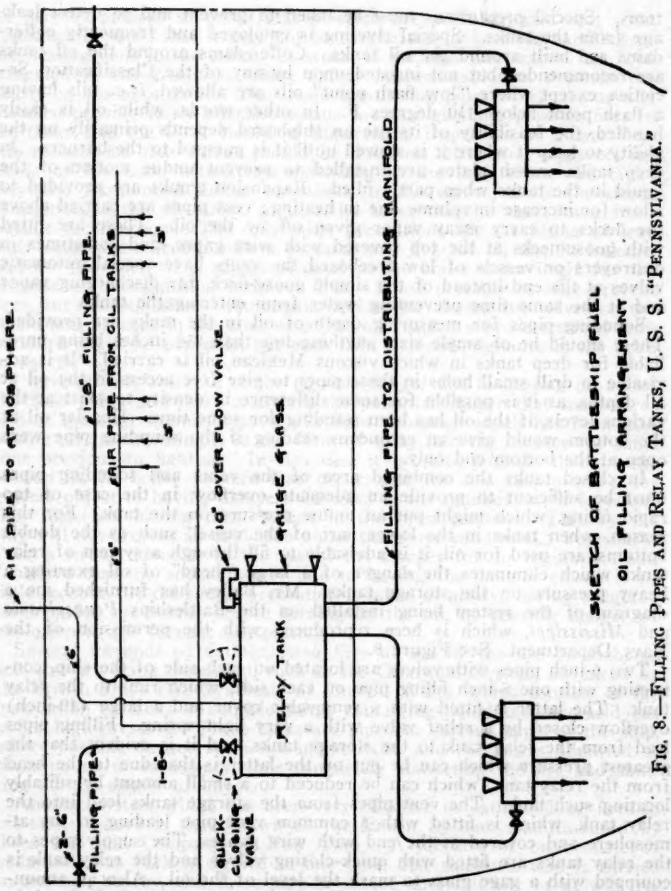


FIG. 8.—FILLING PIPES AND RELAY TANKS, U. S. S. "PENNSYLVANIA."

inches from the bottom of the tank and the other from a point within a few inches of it—not more than four inches. The upper suction is used for regular service, and at all times except in emergency—or when the supply is very low or when the low suction is employed to pump overboard water or very dirty oil which has accumulated at the very bottom of the tank.

Several very serviceable and inexpensive oil installations have been made by Captain Charles A. McAllister, Engineer-in-Chief of the United States Coast Guard, by setting up cylindrical oil tanks either in the coal bunkers or elsewhere for oil storage. This method is well adapted for small vessels.

OIL MEASUREMENT.

For the calculation of evaporative results, fuel used for power, heat value, etc., units of weight are employed, *i. e.*, the pound, kilo, etc. (1 kilo = 2.204 pounds avoirdupoise); but for measurement of bunkers, cargo tanks and in general sales contracts, the oil is figured by volume; thus, in the United States, the usual units are the U. S. gallon (231 cubic inches = 3.785 litres) and the barrel of 42 gallons. The litre and the Imperial gallon (4.54 litres) are used abroad, where the barrel is figured at 41 Imperial gallons (50 U. S. gallons). The Imperial gallon equals about 1.2 U. S. gallons. I understand that some of our oil companies favor the Imperial barrel (50 U. S. gallons) as a matter of convenience, but 42 gallons is the accepted standard.

For statistical purposes, the ton (2,240 pounds) and the "metric ton" or 1,000 kilos (2,204 pounds) are frequently used.

Volumetric measurement of oil should always be based on a standard temperature, the usual figure in this country being 62 degrees F. The Navy Department specifies 60 degrees F., and the correction of 0.4 of 1 per cent. is made for each ten degrees variation from this standard.

Oil meters have been frequently installed in the pipe lines to burners, and as a check on consumption they are of value. All meters, however, are liable to error—and it is not always the same error; besides it may easily happen that the piping arrangement is such as to allow the meter to register while circulating the oil through the system preparatory to lighting up, thus vitiating whatever approach to accuracy the meter might possess.

Tank measurement is in the long run most reliable if properly safeguarded. Valuable data on this subject may be found in an article by Howard C. Towle in "International Marine Engineering" for August, 1912.

Lieutenant Commander Walter B. Tardy, U. S. N., Engineer Officer of the U. S. Battleship *New York*, makes the following statement concerning an apparatus called a "pneumercator," which seems to offer a very accurate means for tank measurement. I understand that this instrument is being applied not only on shipboard, but for shore storage stations as well—and for any sort of liquid measurement in tanks:

"The accurate measuring of fuel oil in tanks that are either being filled, or from which oil is being used, is accomplished by means of the Pneumercator, see description by Mr. H. B. Gregory in the "JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS," May, 1915.

"This instrument provides at all times an absolute check against invoices or withdrawals from the tank, as well as shows the amount of oil available at any time.

"To accomplish this no floats or diaphragms are necessary in the tanks—the instrument working by air pressure, compressed by the head of the oil in the tank.

"The Mercury-Registering Gage can be instantly reset to prove the accuracy of the reading indicated. In case a high or low alarm is desired, no electrical connection is necessary to the tank—the connection being between the Mercury Gage and the Annunciator. This is a most important feature, as it does away with all danger of short circuits and consequent sparking in the vicinity of the fuel oil.

"The Pneumercator has been adopted by the United States Navy to measure the fuel oil in ship's storage and relay tanks, and is now installed, or about to be installed, in all the oil battleships.

"The illustration (Figure 9) shows the recording equipment, complete with annunciators for low alarm, on one of the latest United States battleships (*Arizona*). The gage boards are located at the booster pumps, one gage being connected to each tank.

"The accuracy of the Pneumercator readings is best illustrated by the

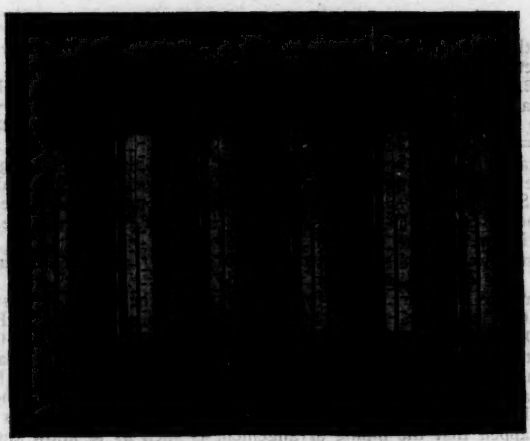


FIG. 9.—PNEUMERCATOR.

(Four units like the above complete the set for the U. S. S. *Arizona*.)

following service incident: On the *New York* the hourly consumption of Peabody burners was determined by the Pneumercator on several occasions. On the acceptance trial of this vessel the fuel oil burned was accurately measured in tanks on deck, under the charge of the Official Trial Board. This measured hourly burner consumption differed by less than 0.1 gallon from that established by Pneumercator readings."

SETTLING TANKS.

If the oil put aboard a vessel contains water in material amount, which by nature of the oil can be separated out by settling, or if water gets into this grade of oil in the storage tanks on board ship, the duplicate system of settling tanks, considered an essential part of all early systems, is a valuable means of preventing trouble in the fireroom—the oil being allowed to stand some hours in one tank while the fuel-oil supply is taken from the other.

The oil companies are now, however, delivering oil for fuel purposes practically free from water; and, with care, water may be kept out of the oil after it has been put aboard the vessel. It is true that the very heavy viscous oils which are much used for fuel contain considerable moisture, but this cannot be removed from the oil in a great degree by any practical means of settling, even when the oil is heated. Besides this, it is an interesting fact that the water bound up in these heavy oils causes little or no trouble in the burners, owing doubtless to its finely divided condition and even distribution throughout the oil.

It would seem, therefore, that settling tanks are a rather useless incumbrance and that the oil can be taken directly from the storage tanks to the burners, the high suction being used ordinarily and the low suction providing means for pumping overboard any water which in the course of time settles in these tanks. The depth of the tank and its location also have a decided bearing on this point, deep tanks resulting in more of the separating process than comparatively shallow compartments, such as double bottoms.

While there is some difference of opinion on the subject, the U. S. Navy Department has dispensed with settling tanks in all classes of oil-burning craft in the service, and uses only a booster pump for lifting the oil to the suction of the service pumps. The booster pump is, of course, no assistance in separating the water from the oil.

CORROSION DUE TO OIL.

Certain grades of the heavier oils contain considerable sulphur, and the question is frequently asked whether or not corrosion from this cause may result. At the opening of the Beaumont fields, particularly, there were many who on general principle prophesied rapid deterioration of boiler surfaces, without giving due thought to the fact that certain kinds of coal having a larger sulphur content than the oil had for years been used for fuel without serious trouble. Experience has demonstrated that sulphur in oil has no bad effect on boilers, except in cases of neglect, when pitting may occur under certain conditions, the same as with coal.

Corrosion of copper heating coils has, however, been noticed in the presence of sulphur-bearing oils, and for this reason it is the recognized practice to use steel coils. Brass and bronze fittings may be used, however, with safety, both in pumps and on pipe lines, and doubtless brass heater tubes could be employed if desired.

OIL PUMPS.

Mr. W. A. Ebsen of the International Steam Pump Company has at my request kindly made the following comments on oil pumps:

"The pumps designed, and usually preferred, for handling crude or fuel oils are of the duplex-piston pattern, except for large capacities accompanied by heavy pressure, where an outside-packed plunger pump is to be recommended.

"With the piston pump there is only one small stuffing box for the piston rod, so that the opportunity for leakage, with its resulting danger of fire, is reduced to a minimum. With an outside-packed plunger pump, there is more or less drip or leakage from the large stuffing boxes.

"The handling of high-gravity fuel oils, running from 30 degrees Baumé up, and quite liquid in consistency, is usually best accomplished by the use of an ordinary duplex pump fitted with brass ring packing in the pump pistons and brass valves and special oil-proof gaskets in the pump-cylinder joints to overcome the solvent action of the oil. For heavy viscous oil, like Mexican crude, the ordinary duplex-piston pump is suitable, provided a size sufficiently large is selected to keep down the oil velocities through the ports and passages and valve seats in the pump cylinders to a minimum. For ideal conditions, the velocity through the valve seats should not exceed a speed of 100 feet per minute for pumps of large capacity, and about half of this for small pumps. For light oils around 40 degrees Baumé the above velocities can be doubled.

"The type of pump ordinarily used for pumping fuel oil to burners, where the oil pressure will not exceed 150 pounds per square inch, is a pump similar to the Snow Duplex piston-pattern pump. In selecting this type for low-gravity oils, it is advisable to use nothing smaller than a 4½-inch x 2¾-inch x 4-inch size, as the ports and valve passages in small pumps are too restricted to operate successfully with oils of this character, and it might be well to remember that the 4-inch, 5-inch and 6-inch stroke duplex fuel-oil pumps have valve areas equivalent to 35 per cent. to 40 per cent. of the piston area and should operate at speeds, say, not to exceed 30 to 40 single strokes per minute each piston, and 10-inch and 12-inch stroke pumps 25 to 30 single strokes. For example, take the 6-inch x 4-inch x 6-inch size operating at 30 strokes—this would represent a piston speed of 15 feet per minute, and the resulting speed of the oil through the valves will be about 40 feet per minute, which is well within the limit."

"These pumps are very often set in duplicate on a cast-iron stand with an oil heater, strainers, by-pass valves, thermometers, gages, etc., and are shown as Fuel-Oil Pumping Systems. See Figure 10.

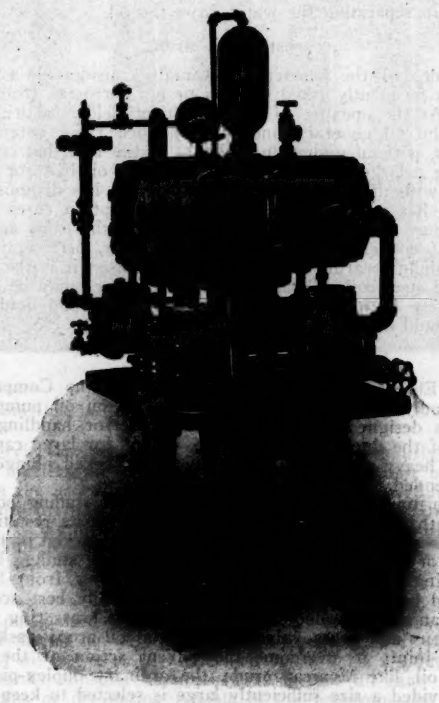


FIG. 10.—FUEL-OIL PUMPING OUTFIT.
(International Steam Pump Co.)

"With this arrangement one pump is operative and the other is a reserve. A pressure governor or regulator is set for the oil pressure and controls the pump automatically. These systems are usually used in connection with low-pressure burners of the steam or air-atomizing type. In rare instances, the single-cylinder pump is used, although in this country the duplex pump is favored.

"For high-pressure fuel-oil systems it is necessary to use pumps designed for operating against oil pressures up to 200 pounds per square inch. For horizontal work, the duplex-pattern pump of the valve-plate style makes a very efficient and satisfactory pump for the service. For naval installations or for marine work where floor space is limited, the vertical duplex Admiralty pump attached to the bulkhead is usually employed. This type of pump is good for 300 pounds maximum oil pressure.

"The same remarks made above with reference to the selection of the size and capacity of the pump, apply to the high-pressure pumps.

"The duplex fuel-oil pump has been universally regarded as the standard in the United States, while in England, for Admiralty purposes, they occasionally use vertical simplex pumps, which, if properly fitted up with suction-air chamber and discharge-air chamber, will give almost as steady and constant a flow of oil as the duplex pump.

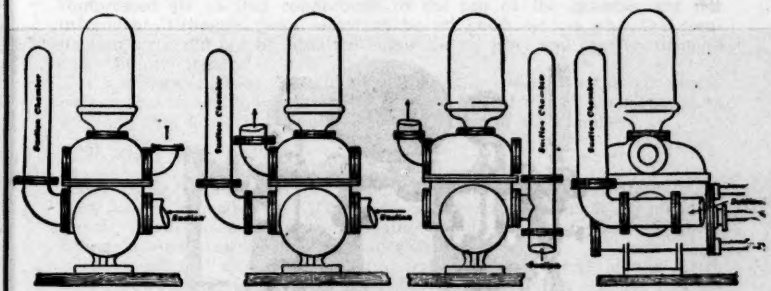


FIG. 11.—SUCTION AIR CHAMBERS.

"The simplex pump, both of the horizontal and vertical type, has better suction qualities than the duplex. The former are usually made longer stroke and permit the use of half the number of valves, which necessarily have to be of larger diameter than in the duplex pumps, and consequently are more favorable for the flow of heavy, viscous oils. On board ship where the bottom of the fuel oil tanks is placed below the location of the pump, the simplex pump, with its better suction qualities, will drain the tank in a more satisfactory manner than a duplex pump. A suction-air chamber should be so arranged as to permit the direction of flow through the suction pipe to cushion against the air or gas contained in the suction chamber, rather than have the flow pass directly into the suction opening of the pump. See Figure 11.

"The pump-valve service ordinarily used in fuel-oil pumps is the plain bronze disc valve spring loaded, or with a wing-guided bronze valve; the latter is used in the Snow heavy-pressure pattern and in the Blake vertical duplex Admiralty pump.

"For large-capacity crude oil pumps we have adopted double and quadruple-beat valves, which pumps have only one valve per section, the valves being of large diameter, with a very low lift. A valve of this type will give full passageway through the valve discs, as would be ordinarily the case with a disc valve, thus necessitating high lift; the oil will pass out through annular openings in the seat and have practically four outlets through the valve. This type of valve reduces slip to a minimum, reduces the wear and is practically noiseless.

"With reference to the manner of fitting fuel-oil pumps, there is some diversity of opinion, but the ordinary construction for stationary service is to install pumps fitted with bronze-lined pump cylinders, iron pump pistons, fitted with spring ring packing and steel piston rods. For marine service it is usual to install brass-fitted pumps, that is, arranged with bronze pump pistons and bronze piston rods. For handling crude oils containing considerable sulphur, steel piston rods and hard cast-iron pump-cylinder linings give better service, especially if the oils contain considerable grit. A fibrous-packed pump piston is not to be recommended, as there will be danger of clogging the burners with shreds of packing passing out with the oil."

The "fuel-oil pumping outfit" described above by Mr. Ebsen is a very convenient, compact arrangement for use with steam atomizers, and simi-

lar outfits are made by numerous burner manufacturers and others. It is likely to be modified to meet the high pressure and temperature requirements of the mechanical atomizer, in which case duplicate heaters of large capacity are essential. An arrangement of this kind designed by Mr. W. A. White of the Washington Engine Works, is shown in Figure 12.

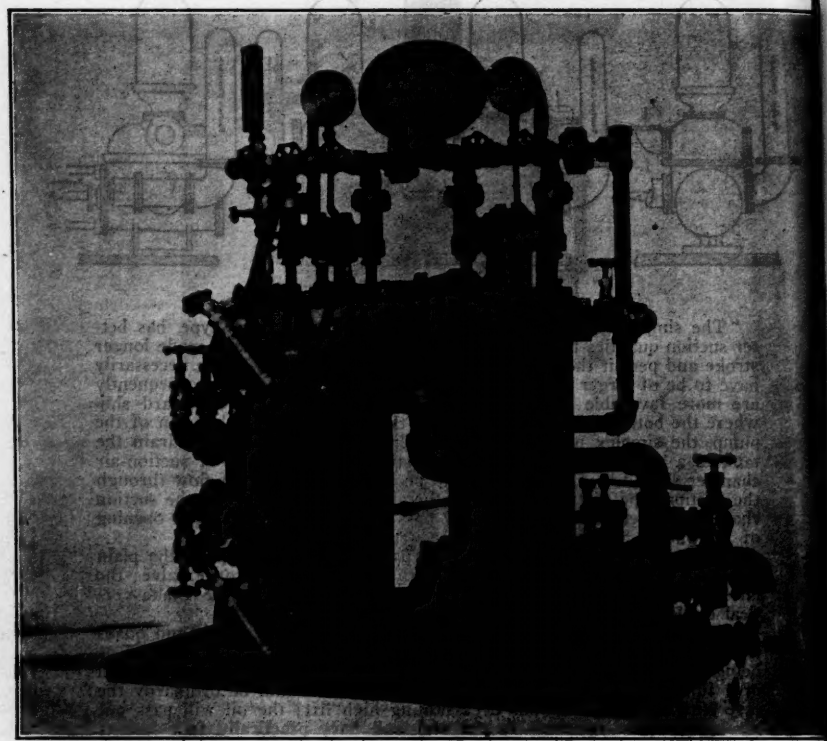


FIG. 12.—WHITE OIL-FUEL HEATING AND PUMPING OUTFIT FOR MECHANICAL ATOMIZERS.

While the reciprocating pump has been very largely used for pumping oil to burners, there are several makes of rotating plunger pumps which give very satisfactory results for this purpose, and have the advantage of giving a very much steadier oil pressure. These pumps utilize the well-known principle of the rotary engine, and experimental tests at League Island have shown them well qualified for use with mechanical-atomizing oil-burning installations.

Air Chambers.—A steady oil pressure at the burners is of prime importance and this can only be secured by the installation of adequate air chambers to neutralize the pulsation of the pumps. The whole thing about the air chamber is to make it tight against air leakage, have it big

enough and provide ample and direct means for the oil pressure to act on the air. Very minute leaks will gradually dissipate the air and destroy the effectiveness of the air cushion. Any sort of connection above the oil level is likely to be a source of leakage; but, on the other hand, the efficiency of the air chamber is greatly increased by charging with compressed air so that connections to the top of the chamber are not infrequent, although there seems to be no good reason why the compressed air could not be admitted below the oil level and pass up through it to the air chamber.

It has been claimed that the rapid depletion of air in the air chambers is due to absorption of the oxygen by heated oil. I am disposed to attribute this, however, to minute air leaks in the air chamber.

PIPING.

For U. S. Naval service the oil piping specified is seamless-drawn steel, with flanges expanded on. The joints are scraped and made up metal to metal. Manila-paper gaskets are allowed on suction piping. Screwed fittings are used on connections under ¾-inch.

For merchant service extra-heavy welded-iron or steel pipe is used, with screwed joints and with extra-heavy galvanized-iron fittings. Flanges are screwed on the pipe and manila paper or card board is used for gaskets, or special oil-proof packing, of which there are several kinds in the market. Rubber is not allowable on account of sulphur in the oil. Copper piping is not used on account of the sulphur, but brass and composition fittings, valves, unions, etc., may be used safely.

The suction piping should be large, the Newport News rule for designed velocity of Mexican oil through suction pipes being not over twenty feet per minute, the oil being heated to reduce the viscosity to about 300 degrees Engler. For discharge-pipe lines they consider 100 feet per minute allowable in small pipes, the viscosity being reduced to 15 degrees Engler or under.

Mr. Bailey states that—

"As we pipe from the service pumps to the oil burners we reduce the speed of the flow near the end of the lines, *i. e.*, we do not reduce the piping in proportion to the oil used, as we find it necessary to reduce the flow in order to maintain the pressure at the burners on the end of the line farthest from the service pumps. With Navy fuel oil, and where we do not make allowance for changing to heavy oil like Mexican oil, we allow about double the speed in the discharge pipe to the burners that is allowed with Mexican oil. For instance, in the *Pennsylvania*, the service-pump discharge to the heaters is proportioned for about 130 feet velocity per minute, the discharge from heaters to burners is proportioned for about 230 feet per minute in 2½-inch and 2-inch pipes, respectively. As the lines reduce we have in 1½-inch pipe 185 feet, in 1¼-inch pipe 195 feet, and in ⅜-inch pipe, to each burner, 128 feet velocities per minute. Our Destroyer practice in regard to piping and oil speeds is substantially the same as that for the *Pennsylvania*."

For valves on suction lines designed for viscous oils, the gate valve is preferable, on account of reduced friction. On delivery lines, globe valves of a regrinding type give satisfaction. There is no occasion to use needle valves. Where fine regulation is required, as in some cases with steam atomizers, there are several types of valves which open gradually on slotted or "V" shaped passages which give better and more consistent results than the needle type. All valves for high-pressure work should be extra heavy with bonnets screwed over, not into, the valve body. Specially designed and packed plug cocks may be used in small sizes for quick action.

Through the courtesy of the Bureau of Steam Engineering, I am permitted to reproduce plans of the oil piping of the U. S. Torpedo Boat

Destroyer *Patterson* (see Figures 13 and 14), together with the following description and notes referring to battleship practice, by Mr. H. B. Gregory of the Bureau. This description summarizes many of the points mentioned above.

Oil Equipment—U. S. S. "Patterson."—"The system comprises storage tanks forward and aft, and two settling tanks in each fireroom, abreast of the boilers, together with the necessary pumps, oil heaters, strainers, etc.

"In each fireroom there are one light-service supply pump, two duplex pressure pumps and two oil heaters, each of sufficient size to heat all the oil used in same compartment to the desired temperature. For raising steam with no source of power available, a hand pump is provided in each fireroom, of suitable size to supply oil at necessary pressure to two burners.

"From the bottom of each forward storage tank a pipe is led to the suction and filling manifold in the forward fireroom. A similar manifold is provided in the engine room connected to pipes from the after group of storage tanks. From each manifold a combined suction and discharge pipe is led to the combined suction and discharge manifold at each supply pump. There are Macomb strainers in both suction and discharge connections between the manifolds and the pumps.

"The supply pumps normally draw from the storage tanks and discharge into the settling tanks, which are cross-connected in each fireroom for maintaining the same oil level in both tanks. In order to prevent overflowing the settling tanks, the starboard tank in each fireroom is fitted with a float, which actuates a chronometer valve in the steam line to the supply pump, automatically shutting it down when the oil in the tank has reached a predetermined height. The supply pumps are also arranged for transferring oil from the forward to the after storage tanks and vice versa. They are also fitted to draw from the settling tanks and to discharge overboard when cleaning tanks. These pumps can also discharge oil to another vessel in emergency, via the deck filling connections. All tanks are filled from the deck via supply pumps, combined suction and discharge pipes.

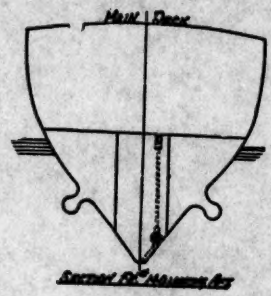
"Extending from just below the mid-depth of each settling tank, with end surrounded by a steam coil, a suction pipe is led to the service pumps, in same compartment and fitted with strainers, at pumps. The service pumps discharge through strainers and heaters, the latter arranged with by-pass to the oil burners. Large air chambers are provided on the pumps' discharge. The cutout valves to the burner lines, across boiler fronts, are fitted for emergency operation from the deck above.

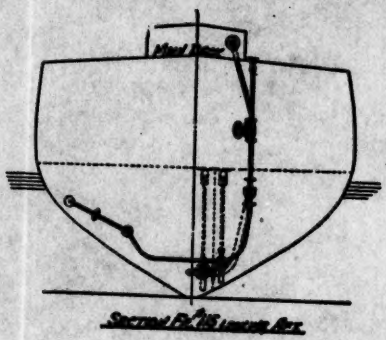
"A hand pump is also provided in the after fireroom for freeing the settling tanks of water and discharging same overboard.

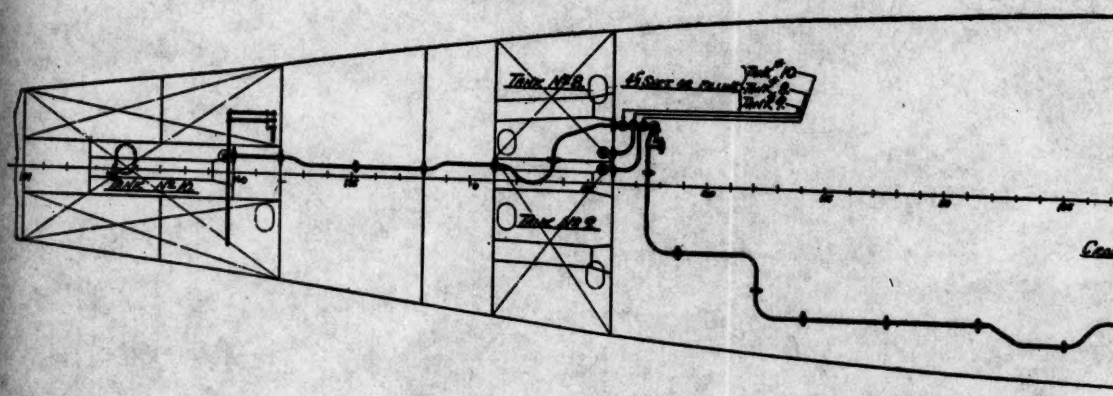
"NOTES.—In the latest destroyer practice the settling tanks have been omitted and the supply pumps are replaced by booster pumps, which perform, in general, all functions previously done by the supply pumps, except that a discharge connection to the service-pump suctions replaces the omitted discharge to settling tank. In some cases the service pumps can also draw direct from the storage tanks in addition to the booster-pumps discharge. High and low suctions were fitted in a few cases in storage tanks, but these have since been abandoned. The ends of all suction pipes in storage tanks are now surrounded by steam coils to facilitate handling of oil. Since the omission of settling tanks, each storage tank is provided with a drain pipe about 1¼-inch diameter, led from lowest point in tanks to a manifold which connect to the booster-pumps' suction, thus permitting water and sediment being pumped overboard by the booster pumps. The float control for supply pumps is not generally fitted.

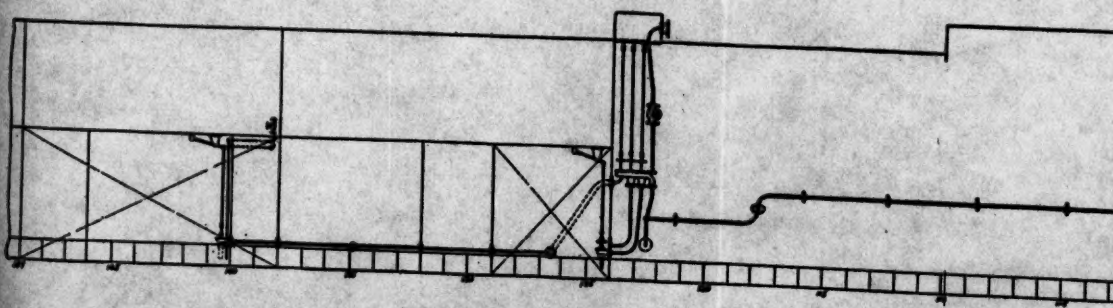
Battleships.—"The practice on battleships is similar to that for destroyers, except as noted below.

"Each storage tank is provided with a high and a low suction, the









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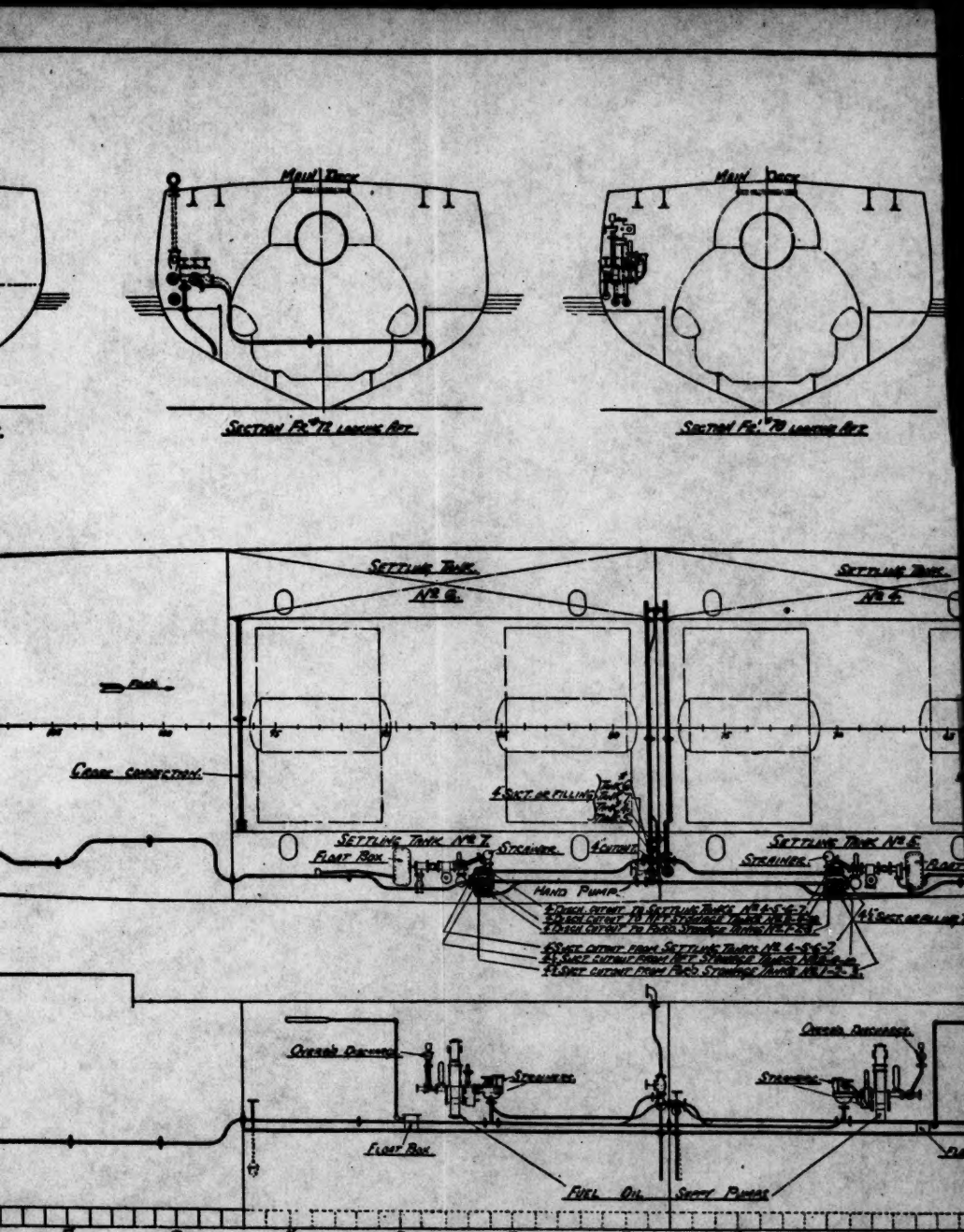


FIG. 13.—OIL PIPING, U. S. S. "PATTERSON."

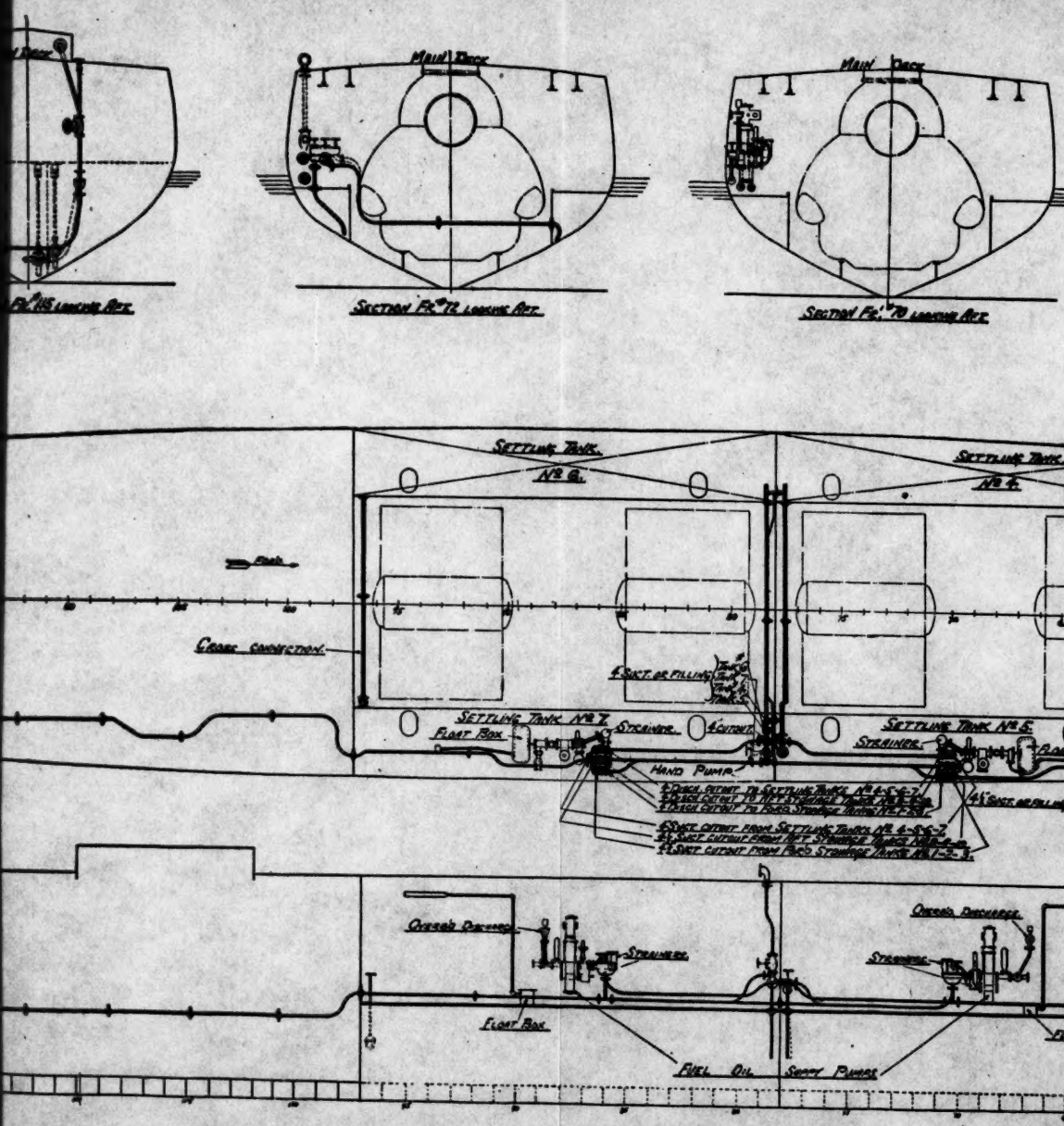
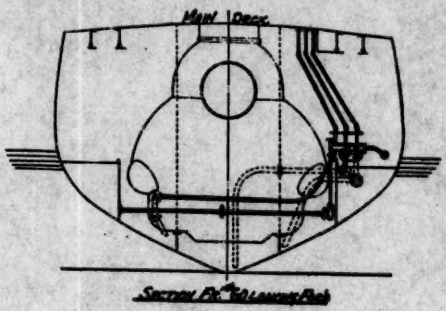
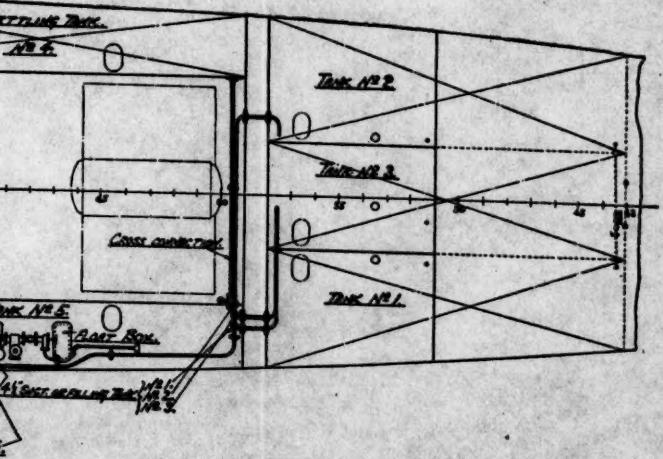
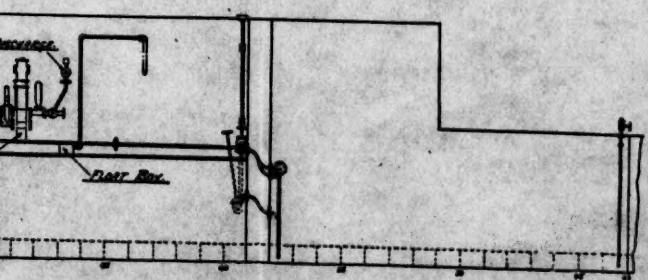


FIG. 13.—OIL PIPING, U. S. S. "PATTERSON."

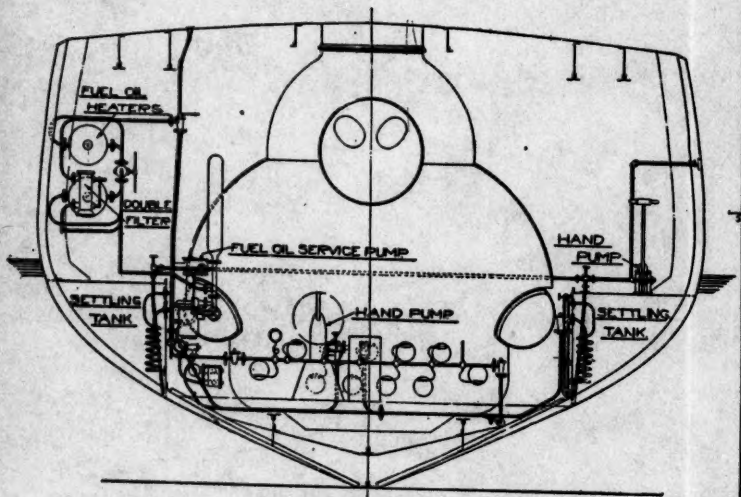




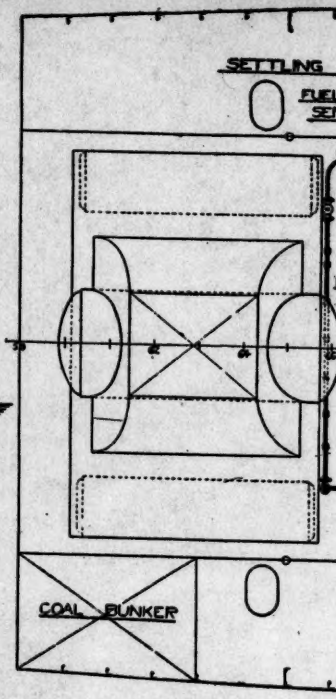


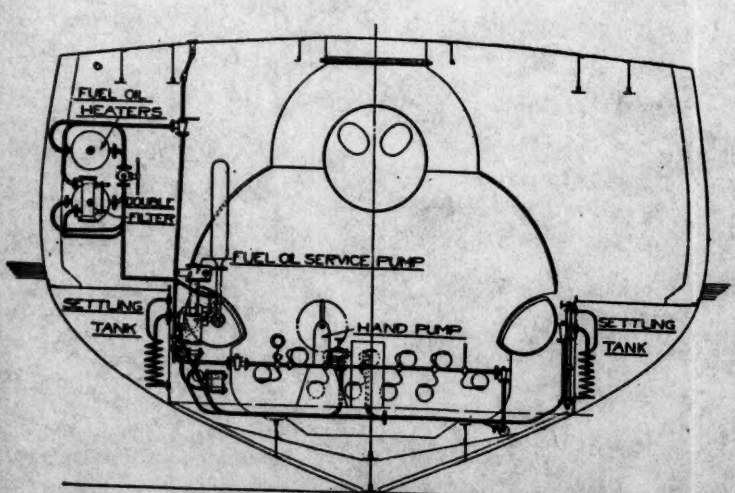
U.S.S. PATTERSON.

FUEL OIL STOWAGE PIPING

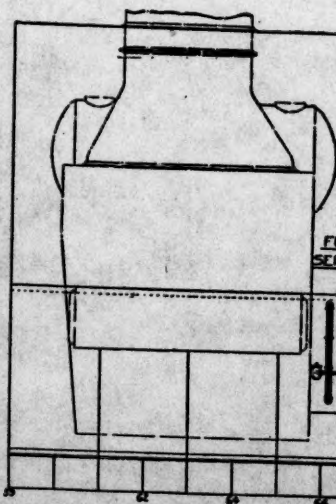


FORD. FIRE ROOM, LOOKING AFT.





AFTER FIRE ROOM, LOOKING AFT.



J. W. Dower, Philadelphia

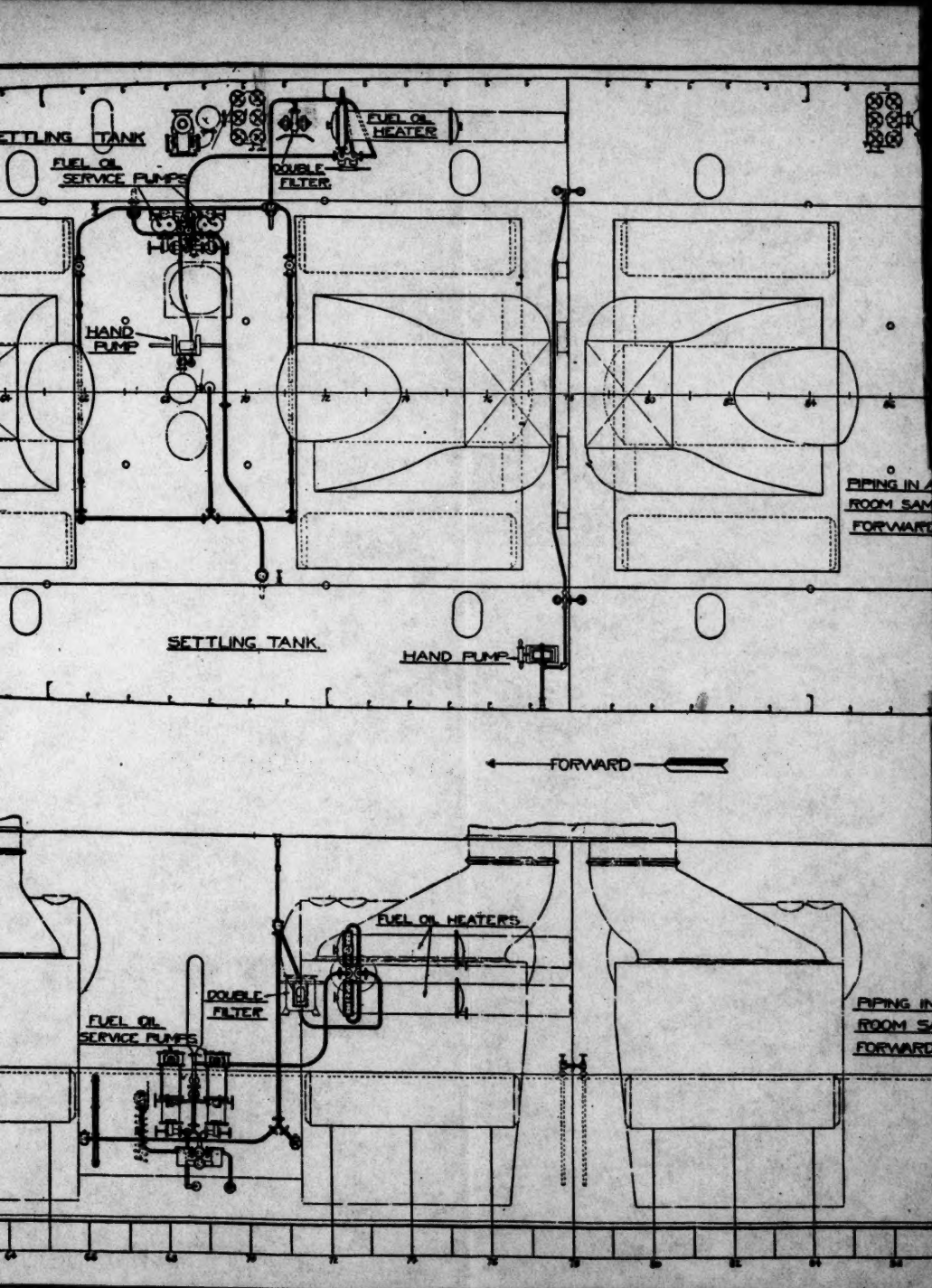


FIG. 14.—OIL PIPING, U. S. S. "PATTERSON."

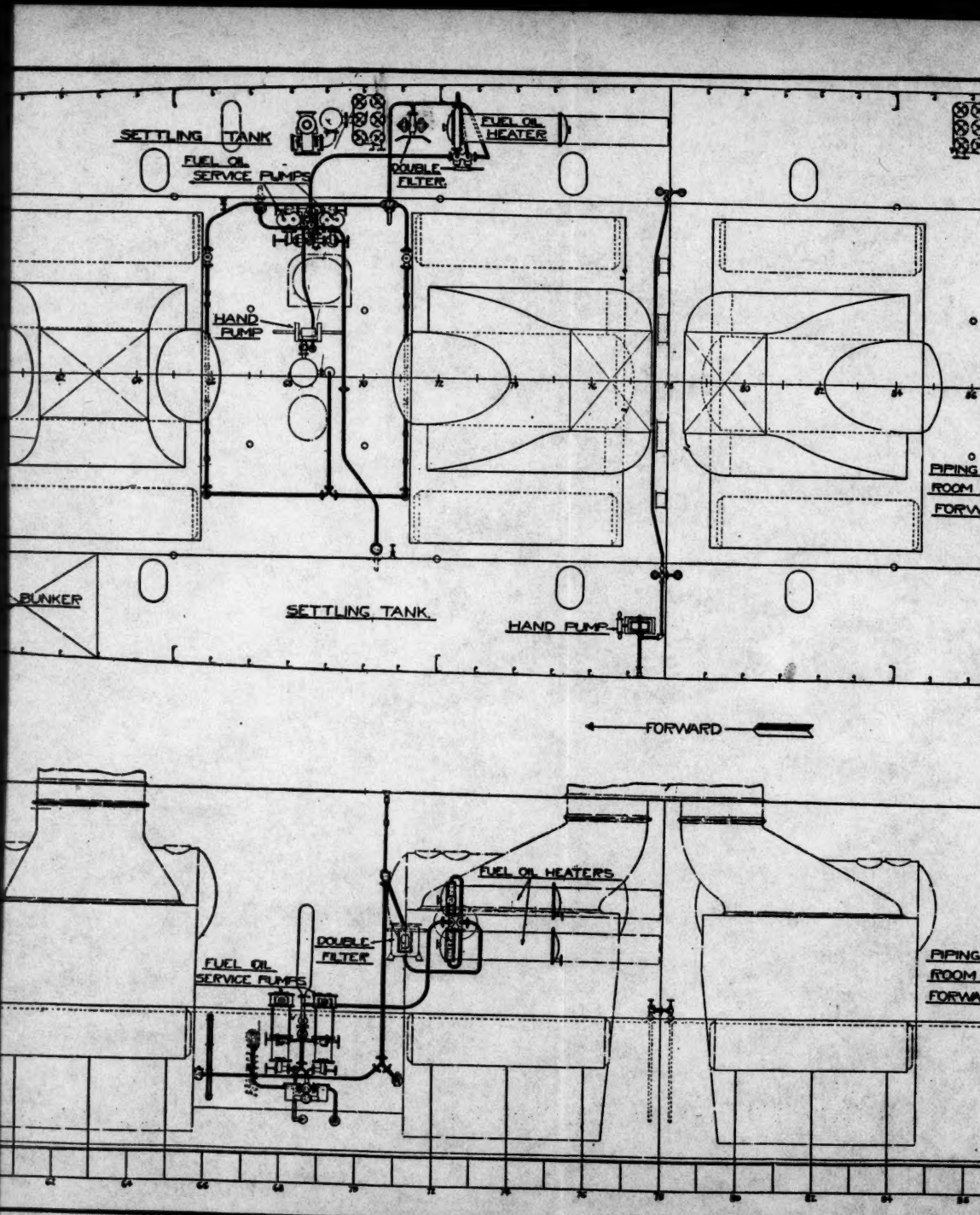
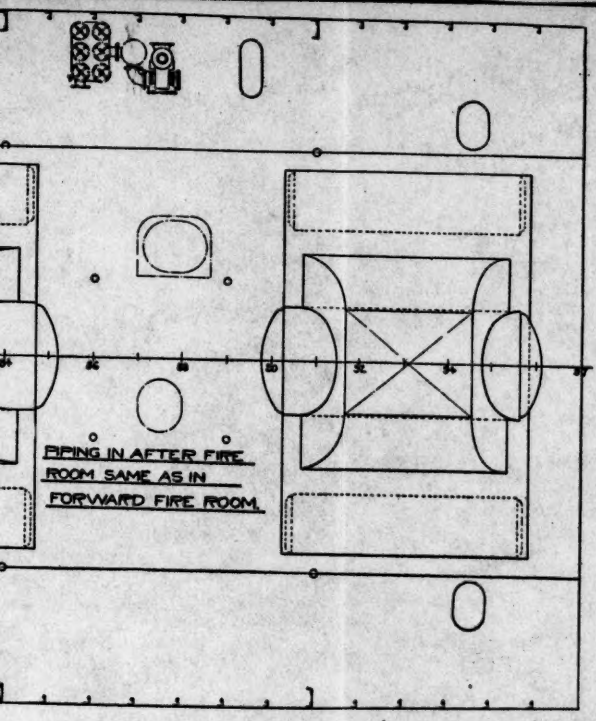
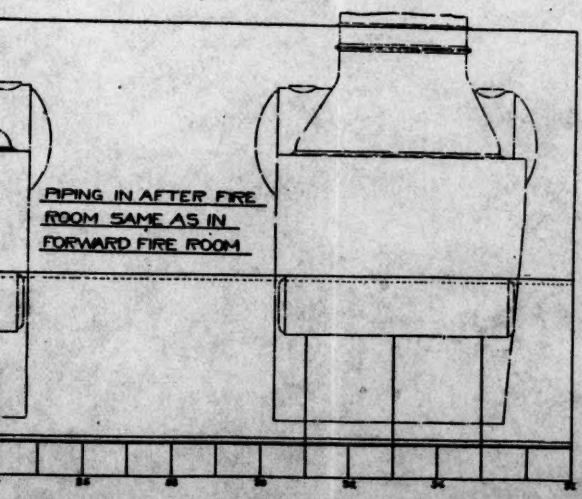


FIG. 14.—OIL PIPING, U. S. S. "PATTERSON."





U.S.S. "PATTERSON."

FUEL OIL PIPING TO BOILERS.

former, extending to within about 12 inches of the bottom of the tank, is the normal suction, and the latter, extending within about 2 inches of the tank bottom, is used only when cleaning tanks or in emergency with low oil in tank. The high and low suctions are often led in two independent mains from the tanks to manifolds, but it is preferable to combine the two, external to the tanks, into a common main to reduce the piping to a minimum. This is easily accomplished by providing two valve manifolds at the tank tops or fitting internal double-suction valves operated from the tank tops.

"The booster pumps on battleships discharge into a main forming a continuous loop common to all firerooms, from which the service pumps take their suctions.

"Settling tanks are not fitted on battleships.

"As the height of the deck filling connections above tanks on battleships is sufficient to produce excessive head on the tanks when filling, relay tanks are interposed between decks into which the filling connections discharge, the relay tanks in turn draining by gravity to the filling manifolds below. In this way the maximum possible head is reduced within safe limits.

"Emergency filling connections are also provided at the vessel's side leading direct to booster-pumps' suctions, the pumps discharging the oil to the tanks, relief valves the full size of pump discharge being provided to prevent excess pressure on the tanks.

"Hand pumps for draining storage tanks are not fitted on battleships, this service being performed by the booster pumps through the low suctions."

STRAINERS.

The comparatively small orifice of the mechanical sprayer necessitates special care being taken in straining the oil. Most makes of burners are fitted with individual strainers, that used in the Peabody burner being shown in Figure 15. The spool is wrapped with three turns of brass netting of 40-to-the-inch mesh, fastened with No. 20 gage brass wire. This is easily renewable when necessary.

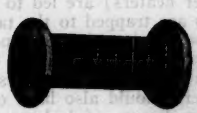


FIG. 15.—STRAINER USED WITH PEABODY BURNER.

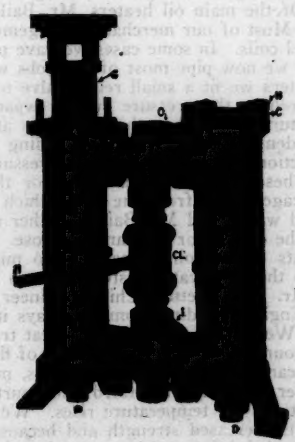


FIG. 16.—OIL STRAINER.
(Schutte & Koerting Co.)

Strainers of the McComb type are also used both on the pump section and delivery lines. See Figure 16. These are fitted in duplicate, so that alternate cleaning is possible without allowing the oil ever to pass unfiltered. There is little variation in design of filters, but considerable difference in practice as to size of mesh, which varies from one-quarter inch to one-sixteenth inch on the suction strainers and from one-sixteenth inch to one hundred mesh to the inch in the discharge strainers, the latter being rather too fine and fragile for good practice. Mr. Bailey recommends pressure gages on each side of the strainers, so that undue fouling will be indicated by the difference in pressure. There is some question as to whether strainers are needed on both suction and delivery oil lines. This will depend greatly on the oil—but the viscous oils hold tenaciously every foreign substance that gets into them, and straining facilities should rather be increased than diminished. At all events, the oil delivered to mechanical-spray burners must be as clean as practicable to prevent clogging, and to minimize wear of the orifices.

HEATERS.

Viscous oils, particularly when used with mechanical atomizers, have widened the field and increased the importance of oil heaters. Where formerly a single small heater, operated with the exhaust steam from the oil service pumps, was found adequate for the lighter oils and steam or air atomizers, it is now necessary, in order to use, or be prepared to use, the heavy oils on the market with mechanical spray burners, to install heating coils around the pump suction in the storage tanks, and to have in or near the fireroom, heaters using live steam and sufficient in capacity to heat the oil to perhaps 270 degrees or 280 degrees F. With mechanical atomizing burners, the heater is quite as important as the pump, as with viscous oil the plant is inoperative without it. Duplicate heaters are therefore necessary, one for regular operation and one for spare; or for large plants, what is perhaps better "commercial engineering" and quite as effective, it is quite common to install three heaters, two being used together in regular operation, and one spare.

Of the main oil heaters, Mr. Bailey says:

"Most of our merchant arrangements show three oil heaters fitted with steel coils. In some cases we have piped these with the steam in the coils, but we now pipe most of our jobs with the oil in the coils. In all of our heaters we fit a small relief valve to the oil connection; this is necessary to relieve the pressure due to expansion of the oil in case steam should be turned on when the oil valves are closed. The drains for the steam condensed in the heaters (including the bunker heaters) are led to an inspection tank, those from the pressure heaters are trapped to the tank."

These inspection tanks are for the purpose of detecting any possible leakage of oil from the coils which might ultimately get into the boiler-feed water, and Mr. Bailey further recommends placing a small test cock in the drains for the same purpose. All heaters should also have outside joints on the oil connections to minimize the danger of leakage of oil into the feed-water system through heater drains.

Mr. J. F. Metten, Chief Engineer of the William Cramp & Sons Ship & Engine Building Company, says in regard to design of heaters:

"We use the formulae for heat transmission given in the tables, which, of course, vary with the velocity of flow through the heating tubes. Where we can, we use four-pass heaters, making the first and second passes of larger area than the third and fourth, on account of the change in viscosity as the temperature rises. We use seamless-steel tubing on account of its increased strength and because this material will permit of better expanded joints being made than is possible with softer metal such as copper."

The film heater invented by Mr. L. D. Lovekin and manufactured by

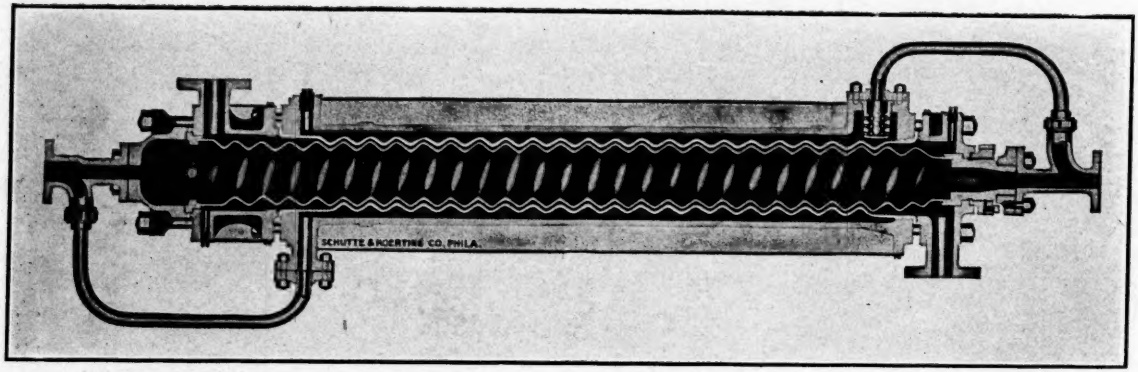


FIG. 17.—FILM OIL HEATER.
(Schutte & Koerting Co.)

the Schutte & Koerting Company is a most ingenious design, and tests have shown it to be the most effective heater yet devised. The oil is forced in a thin film between two steam-heated surfaces of such shape that the oil is continually being mixed or stirred in passing through the heater. The construction will be apparent from the illustration, Figure 17. The remarkable results obtained with this type of heater used for heating feed water are described in an article in the "JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS" for May, 1915, by Professor Leo Loeb. Mr. Lovekin's work has upset the old rules relative to heat transmission.

Most of the shipbuilding companies that install oil-burning apparatus make oil heaters, one of which is illustrated in Figure 18, showing the Union Iron Works design.

It will be evident, from what has already been stated regarding viscosity, that heaters are necessary in the storage tanks and bunkers to permit of the oil being pumped to the main heaters, where its viscosity is reduced sufficiently for atomizing. The tank heaters consist usually of coils of iron pipe about 1½-inch diameter located near or around the pump suction. These coils must be able to heat the oil as it enters the suction sufficiently to reduce the viscosity to about 375 degrees Engler, or lower.

In the case of fuel tanks or bunkers, it would not seem necessary to heat the oil throughout the entire tank, and thus in the case of the double bottom attempt to "warm up the whole ocean," providing local heating in the immediate vicinity of the pump suction could be carried out rapidly and uniformly enough to heat the oil as it was pumped away. In this case the size and heating surface in the heating coil should be proportioned to the rate at which the oil is pumped out of the tank rather than to the size of the tank. The situation relative to cargo tanks is different, owing to the high rate of speed at which the oil is handled by the cargo pumps.

Prevailing opinion seems to be opposed to carrying very viscous oil in the double bottoms, on account of the very large heaters necessary; and the usual practice also is in favor of heating the oil throughout the entire tank previous to starting the pumps. Thus, in the cargo tanks of oil-carrying vessels, flat coils are often installed near the bottom of the tanks in addition to the coils around the suction, the combined heating surface of the two sets of coils being figured at the rate of 1-10 of a square foot of heating surface per barrel of oil of that total capacity of the tank. About 40 per cent. of this surface is allotted to the suction coils and 60 per cent. to the flat coils. The Southern Pacific Company's practice is to put Mexican oil on board at 110 degrees F. and maintain about that temperature during the voyage rather than heating up the cargo when discharging. The economy of this policy depends of course on the length of the voyage.

OIL FUEL FOR GALLEY PURPOSES.

The small consumption this involves hardly warrants mention here, but evidence is accumulating that satisfactory methods for cooking and heating with oil are being developed. Published circulars of the various devices on the market seem to avoid detailed description of the apparatus and to enlarge on workmanship, material and "years of experience" of the inventors. However, the field is promising and worthy of investigation by owners of ships using oil fuel.

EARLY METHODS OF BURNING OIL.

An authentic history of the first developments in methods of burning liquid fuel is much to be desired, and I had hoped to include a brief

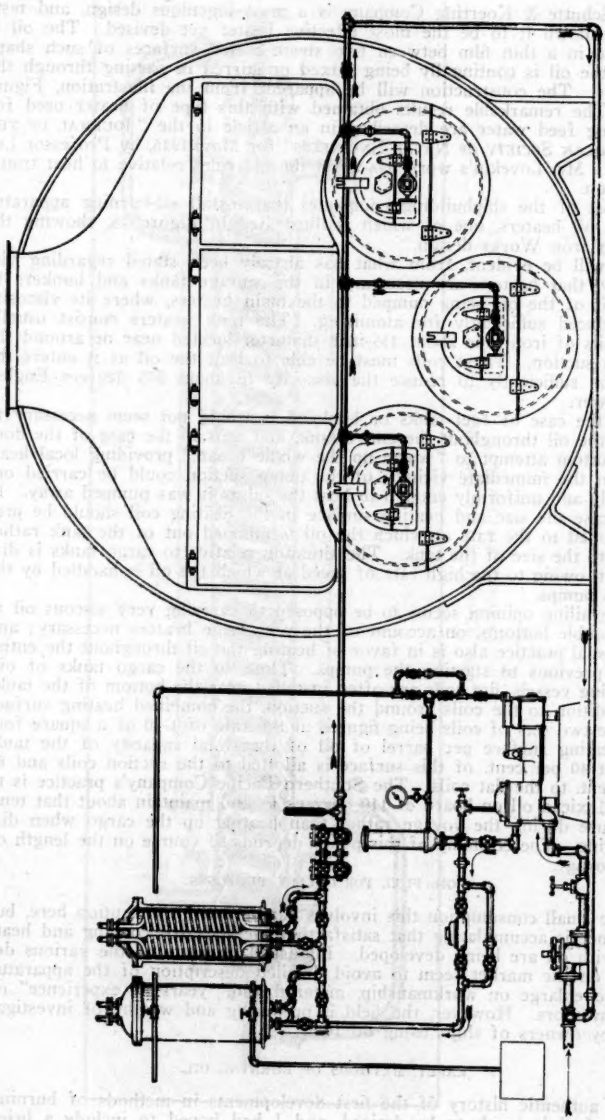


FIG. 18.—OIL HEATERS. (UNION IRON WORKS CO.)

reference to it in this paper. I am indebted to Mr. George F. Gourley of the U. S. Patent Office for much valuable assistance in looking up this subject, and he has called my attention to an English patent granted to Alexander Cruikshank, in 1839 (eleven years before Young's patent), for a method of producing "liquid tar" from coal, and including "certain new and advantageous arrangements for applying to useful purposes the heat and light to be obtained from such tar and from oils, etc." Cruikshank shows how the "heat attainable from liquid fuel may be applied to the generation of steam," his method being to inject the oil, by means of a "syringe" worked by an engine, into the furnace, on and among a lot of hollow clay balls, which being brought to an incandescent heat, aided in the combustion of the fuel.

On June 27, 1865, an English patent was taken out by Brooman as a communication from Schpakofsky and Stange of St. Petersburg, which shows a small apparatus for blowing a blast of air at right angles across the end of an oil pipe. Apparently these people had no thought of applying the device to boilers, but they claim broadly "burning liquid hydrocarbons in the state of spray formed by and mixed with a blast of air."

Six years before this (in 1859) Warner and Tooth took out an English patent for forcing liquid hydrocarbon into the tuyére of a blast furnace. They considered the air only as a supporter of combustion and did not mention any spraying effect, but the combination undoubtedly acted as an effective atomizer.

Following the Russians a few months (Oct. 16, 1865), an English patent was granted to Wise, Field and Aydon. This Field was the famous "tube within a tube" boiler inventor, and Aydon afterwards did considerable work with oil fuel. These three inventors claimed eleven inventions in this one patent—including improvements in boilers, novel methods of evaporating water with superheated steam, water purifiers, step grates and down-draft furnaces, and, eighth on the list, and not given exceeding prominence, notwithstanding its apparent novelty and importance, a method of using petroleum by injecting it by means of superheated steam into the furnace. They describe several atomizers, and then follows this significant statement—"other forms of injector may be used for injecting the petroleum if preferred."

Certain authors have given credit for the epoch-making invention of the oil sprayer to Wise, Field and Aydon, or their contemporaries, Schpakofsky and Stange, but the above reference to "other forms of injector" seems to me to indicate that some earlier experimenter deserves this honor, possibly Warner and Tooth, or the American, Hill, who in 1863 took out a patent in which he claimed "the employment or use of a mixture of hydrocarbon liquid with steam as fuel in furnaces."

It is most interesting to note, also, in passing, that an American patent was granted to one Frederic Cook, in January, 1868, for an apparatus which sprayed oil by mechanical means and for which the following claim is made: "The introduction and distribution by centrifugal force of liquid hydrocarbon into furnaces as fuel, etc." Cook forced the oil into one end of the spindle or shaft of a device which was rapidly revolved by power, the oil being thrown off radially as a spray from the other end of the shaft which was fitted with a suitable disc or cone.

This idea was revived in 1902 by Harvey D. Williams, one of the Technical Secretaries of the U. S. Liquid Fuel Board, but did not get out of the experimental stage. I have just learned, however, that "rotary burners" working on this principle, operated by electric motors, are in successful use on the Pacific Coast for house heating and cooking.

Undoubtedly the earlier attempts to burn oil were along the lines of surface combustion from pans, stepped or inclined troughs or plates, or by wicks or absorption by porous substances, and also by various methods

for heating and vaporizing the oil exterior to the furnace, and burning the vapor.

The open-pan method is still successfully used in small furnaces for heating and drying where the combustion is of limited capacity and at a more or less uniform rate. This form of apparatus has been applied to boiler furnaces, as, for example, in the device patented by Ludwig Nobel, in Russia in 1883. Experience has shown, however, that except for very small powers it is not a practical method of using oil fuel for steam purposes. This was again proved only a few years ago by a test conducted at the Boston Navy Yard, where a very successful metallurgical furnace designed by Oakleigh was applied experimentally, but without satisfactory results, to a stationary boiler.

There have been many advocates of the vaporizing principle, *i. e.*, the conversion of the oil to vapor or gas before admitting to the furnace. Patents involving this idea have been issued in great numbers, but the only one to attract attention for boiler work of late years is that granted to F. Koerting (U. S., 1905), covering the process in which the oil is heated considerably above the normal flash point, but retained in liquid form and the vapor prevented from distilling off by maintaining the oil under pressure. It is then conveyed to the burner and injected into the furnace, where the pressure is suddenly released and a portion of the oil is converted into vapor by the heat stored in it—the rest being atomized in the usual way. This process patent was at first thought to have covered the entire field of mechanical atomizing and attracted much attention until it was found that the viscosity of the oil was the controlling feature, and heating the oil was of value only as a means of reducing the viscosity.

Over forty years ago Commodore Isherwood summed up the situation relative to oil burning for steam purposes by stating that atomization or spraying "is the only method that has been attended with success." This holds good today.

ATOMIZERS: STEAM, AIR, MECHANICAL.

It is also true that the three methods referred to above in the early patents are still employed in boiler work—*i. e.*, spraying by means of steam and compressed air and the mechanical application of centrifugal force. In the latter case, however, the simpler method of utilizing the oil pressure for giving the liquid a rapid whirling motion inside the burner tip has practically displaced the rotating spindle and plate.

Other methods for the production of an oil spray by mechanical means are referred to in the English patent to Norton and Hawkesley, 1867. They describe methods of forcing the oil between two surfaces pressed tightly together by a spring, or allowing two small jets of oil to impinge on each other at high velocity, or allowing a single jet to impinge on a plate or other obstacle. My own experiments with these methods have been quite unsatisfactory, and probably any success which Norton and Hawkesley might have had was due to the use of an air blast admitted with a whirling motion around the atomizer.

I have been informed that recently promising experiments have been made with mechanical sprays produced by forcing *highly heated* oil under pressure through small orifices or narrow slots without giving the oil any rotary movement and therefore without the application of centrifugal force. The successful mechanical atomizer as we know it today, however, depends on the principle of giving to the oil a rapid whirling motion in a chamber in the tip and liberating it suddenly from a small orifice concentric with the axis of rotation. The centrifugal force engendered sprays the oil in the form of a hollow cone, the minute particles of oil flying off radially. The spray itself has no rotating movement unless this is brought about by a whirling body of air admitted around the burner tip.

The flat-spray mechanical atomizer has as yet attained no commercial prominence, though it seems to have possibilities and certain advantages, particularly for low draft conditions, and in furnaces of low head room. It is possible to flatten the flame from a round spray burner by special regulation of the air for combustion—the Babcock & Wilcox application of this idea being used in several U. S. battleships.

Burners which spray the oil by centrifugal force by giving the liquid a whirling motion inside the tip are so closely allied to similar devices for spraying water that doubtless some sort of link exists. Just who is to be credited with the first application of this principle to oil burning I do not know, although published statements seem to agree that the Koerting Brothers abroad were among the pioneers in introducing the mechanical spray—particularly on shipboard.

It is to the British Admiralty, however, that we owe the modern development of the mechanical atomizer. In a few years following the discovery of Spindle-top, they applied this type of burner to water-tube boilers operating under forced draft at high capacity, and thus attracted attention to its larger possibilities for marine service. In 1907 the United States Navy followed the example of England and really introduced the mechanical atomizer in America, and with the increasing production of oil, its use has been rapidly applied to the merchant marine and it is today recognized in its many varieties as the standard type for extended sea service—though for harbor use or where fresh water is easily obtained, the steam atomizer has a deserved standing which it will not easily surrender.

As an *atomizer, per se,* nothing that I know of can exceed the effectiveness of the steam atomizing oil burner. I have many times looked into a boiler furnace operating with this type of burner and been able to see every brick and joint of fire clay all glowing with incandescence, not a vestige of flame being present. Such a condition of flameless combustion may be obtained with air as an atomizing medium, but cannot, so far as I know, be obtained with mechanical atomizers. Owing to the high expenditure of steam, it does not pay to regularly operate under these conditions, but I am speaking of the effectiveness of the various types as sprayers.

But in economy of fuel, also, for steam production the steam atomizer is second to none. A widely circulated statement, by a high authority on oil burning, makes it appear that there is a difference in economy of fuel between the steam and the air atomizer of 12 per cent. in favor of the latter—though it is claimed that this is reduced to 4 per cent. by deducting the cost of compressing the air. I find it hard to accept this first statement as a fact. It may be quite possible, as stated by Mr. E. G. Spilsbury in his discussion of Mr. W. N. Best's paper in the Proceedings of the American Institute of Mining Engineers, 1914, that steam-atomizing oil burners are objectionable in steel furnaces owing to the liability of hydrogen from the dissociated steam being absorbed by the metal, thus making it brittle; but for boiler purposes there is no objection to steam atomizers, and cheapness and simplicity have resulted long ago in their general adoption on shore. In my experiments with stationary boilers of the Babcock & Wilcox design in California, in 1902, I repeatedly obtained boiler efficiencies exceeding 82 per cent., with steam consumption by the burners less than 2½ per cent. of the output of the boiler, giving, after deducting the steam used by the burners, nearly 80½ per cent. *net* efficiency. Doctor D. S. Jacobus obtained nearly 81½ per cent. *net* efficiency with steam atomizers at Redondo in 1908. I question if it is possible to exceed these figures one iota by the use of air atomizers. There is certainly no such gain as 12 per cent., or even 4 per cent. I think there is a general misapprehension in regard to steam atomizers and that this is due to calculations based on tests made under

adverse conditions and to academic considerations based on the fact that air supports combustion and steam does not.*

The steam atomizer is further frequently compared, to its disadvantage, with the *mechanical atomizer*—it being contended that as the latter uses no steam directly for atomizing, whatever percentage of the fuel expense is represented in operating the steam atomizer goes into the coffers of the purchaser who may replace the steam sprayer with a mechanical atomizer. Admitting, for the sake of argument, that the steam consumed by the steam atomizer exceeds somewhat the extra cost of operating the pumps at the higher pressure and heating the oil to the higher temperature required by the mechanical atomizer (I know of no reliable tests to determine this point), I think that the answer is found in the fact that no authentic tests on record, using mechanical atomizers, show boiler efficiencies as high as those obtained with steam atomizers; in fact, the steam atomizer holds the record for economy.

It is claimed further, by some, that the oil atomized per burner per hour by a mechanical atomizer is greater in amount than that atomized by a steam or air atomizer. In general, the reverse is true—but this is rather a question not of burner, which can be made any size, but of air admission, which rather favors the steam or air burner. It is true that as at present ordinarily installed, with the air for combustion admitted underneath the broad flat flame of the usual type of steam atomizer, the number of burners which can be used with a boiler of given size is considerably less than the number of mechanical atomizers which can be installed. In the latter type, the air for combustion is admitted around the burner through the boiler front. By using a large number of burners, therefore, the mechanical atomizer is capable of giving very high boiler capacity with forced draft—higher than the steam atomizer as at present installed, though I believe the possibilities of this latter type in the matter of ultimate boiler capacity have not been fully developed. Outside of naval work, where very high forcing is required, the steam atomizer fills every requirement as to boiler capacity.

The real advantage of the mechanical atomizer lies in its simplicity as compared with the *air atomizer* and its saving of fresh water as compared to *steam atomizers*. The latter are cheaper to install and fully as simple to operate, and in some respects they surpass the mechanical type. For harbor service, therefore, they will long find a field of valuable service in marine work.

In speaking of air atomizers it should be noted that there is little or no difference between the types using air at 30 pounds and over, and steam atomizers; in fact, the two styles are practically identical. The low-pressure air burners (air at a few ounces) are of different design and in a class by themselves. A representative burner of this kind is that known as the Lassoe-Lovekin Burner, and it was installed on many of the earlier ships, with much success, by Mr. Lovekin.

Steam atomizers of every conceivable design have been evolved and

*Since this was written the writer has had some interesting correspondence with Mr. William N. Best, in whose book, "The Science of Burning Liquid Fuel," the statement referred to appeared. Mr. Best has applied his burner to many styles of furnaces for heating, etc., in various industries and uses the term "furnace" to indicate this sort of installation as distinguished from boilers. His conclusion that compressed air was more economical than steam was based on tests of two rolling-mill furnaces of similar size and construction, one equipped with air atomizers, and one equipped with steam atomizers, both operating at 80 pounds pressure. Mr. Best points out also the objection of using steam for atomizing in furnaces remote from the boilers. While the paragraph in Mr. Best's book limits the statement of relative efficiency of steam and air atomizers to "furnaces" (meaning other than boiler furnaces), quoted references fail to emphasize this distinction which is very naturally explained by the fact that the term "furnace" is applied quite as freely to boiler installations as to those of other types and, it will be admitted, with entire propriety. It is to be regretted that a meaning has been attached to Mr. Best's figures which he did not sanction nor intend.

are used extensively on shore and for harbor work. The round-flame type is best adapted to the Scotch boiler furnace, though on account of its usual superiority in economy of steam used for atomizing, the flat-flame type is often installed with Scotch boilers. Vice versa, round-flame steam atomizers may be used in water-tube boiler furnaces, but here the flat-flame burner is of undisputed superiority. A good burner of this type, properly operated, should not use over 0.35 pound of steam per pound of oil atomized.

Steam atomizers (in fact all burners) were classified by Mr. Frank Van Vleck, Technical Secretary of the Liquid Fuel Board (see Board's report), and his work has been extensively quoted by writers on oil burning. As far as I know, the classification is not used in the "trade," and about all the distinction which is necessary in addition to "round and flat flame" mentioned above, is "outside mixer" and "inside mixer;" *i. e.*, in one, the steam (or air) and oil come together outside the burner tip, and in the other, they are "mixed" inside the tip. There is little to choose between the two types, although the proportion of steam and oil, and the oil output, in the outside mixer is very slightly affected by variation of the steam pressure—while on the other hand, any variation in the steam pressure in the inside mixer alters the rate at which the oil is delivered, as well as the proportion of steam and oil. But the main consideration in any burner is simplicity of design and ease with which it may be cleaned and repaired. Furthermore, the "atomization" of the oil in any burner, mechanical or otherwise, takes place *at the orifice or outside of it*, and such things as "mixing" and "atomizing chambers" in the inner workings of the burner are mainly "talking points" for the salesman. The best steam atomizer I ever saw was made by Mr. Adam Heberer, of San Francisco, out of a simple piece of gas pipe—the only trouble with it was that it did not wear very well and was difficult to clean.

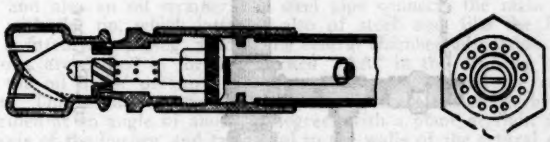


FIG. 19.—STAPLES & PFEIFFER FLAT-FLAME INSIDE-MIXER STEAM ATOMIZER.

A steam atomizing burner of the inside-mixing flat-flame type is shown in Figure 19. It is made by Staples and Pfeiffer, and has gained a good reputation in marine work on the Pacific Coast.

A type of outsider mixer is shown in Figure 20.

TYPES OF MECHANICAL ATOMIZERS AND METHODS OF ADMITTING AIR FOR COMBUSTION.

There are now so many successful designs of mechanical atomizers on the market that I am not able to include a description of them all in this paper. With some reluctance I have therefore decided to illustrate only those designs which have attained prominence in America. Many interesting inventions have been made abroad, notably in England, and there are many prominent names identified with the burning of oil fuel. However, all the oil burners work on the same general principle, and those used in this country will be sufficient to illustrate the state of the art. The following list is arranged in alphabetical order:

Bailey Burner.—Made by the Newport News Shipbuilding and Dry

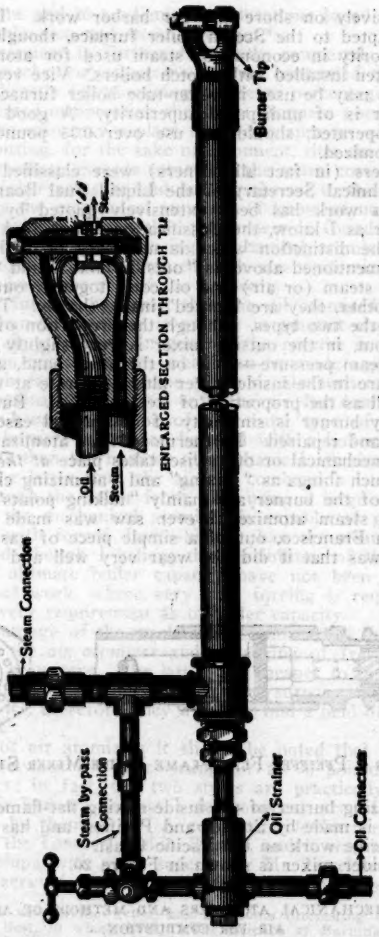


FIG. 20.—PEABODY FLAT-FLAME OUTSIDE-MIXER STEAM ATOMIZER.

Dock Company. This burner is shown in Figure 21. Mr. Bailey states that one of his assistants, Mr. Mortimer, was associated with him in the invention of this burner. A quick detachable coupling fastened with a yoke is used to hold the burner in position and a wooden handle may be screwed into the burner elbow to facilitate handling. A steel tube is screwed into the coupling casting and on the other end of the tube is screwed a composition nozzle which is adapted to receive a steel tip provided with a central chamber 3/16-inch in diameter. A special plug of adjustable length is screwed into the end of the chamber, so that the actual volume of the chamber in which the oil is given its rotary motion is ad-

justable. Grooves in the threaded portion of the tip are provided for delivering the oil under pressure to an annular space just outside the central chamber. Oil passes to the central chamber through two small openings or round channels drilled in the tip at an angle of about 45 degrees to a plane at right angles to the axis of the burner. These channels are tangential to the sides of the central chamber, so that as the oil enters the chamber it acquires a rapid whirling motion and issues from the orifice in the tip in a finely divided conical spray. The Bailey design of air admission is shown in Figure 22 as attached to the Babcock & Wilcox Boilers of the Steamship *Matsonia*.

This consists of a cast-iron grid of the shape of a truncated cone, the walls of which are cored so as to provide channels for the admission of the air. The passages are curved to give the air a rotary motion. Outside this grid there is a cover which may be revolved by means of a lever; this cover is slotted to correspond with the air passages in the truncated cone, and thus serves as a means for regulating the quantity of the entering air or for closing it off entirely. Inside the cast-iron grid there is another truncated cone of different dimensions designed to protect the tip of the burner from direct impact of the air; this is shown partly in section in the drawing. The burner is installed through the small end of the truncated cone, and in this particular design the burner is inclined slightly upward from the horizontal line in order to give an upward sweep to the spray as it enters the furnace. The design shown is adapted to operate natural draft, but it is also applicable to forced draft.

Bureau Burners.—(Bureau of Steam Engineering, U. S. Navy.) The first Bureau Burner, Type Y (see Figure 23), was designed to be used at the Fuel-Oil Testing Plant at League Island, where, after certain modifications made by Commander Hyland, it gave excellent results in the boiler tests at that plant. In this burner a quick detachable yoke coupling is used and also an oil strainer. A steel pipe connects the main body casting with the tip, which latter is also of steel, and, like the Bailey burner, is fitted with a plug, making the central chamber adjustable. Two small holes are drilled in the tip, marked "AA" in the drawing, which deliver the oil under pressure to the annular space around the central chamber. This annular space connects with the central chamber by four holes drilled at an angle of about 26 degrees with a plane at right angles to the axis of the burner, and tangential to the walls of the central chamber.

The Navy Department standard fuel-oil burner has recently been modified as shown in Type "I," Figure 24, this design originating with Lieutenant Starr, who succeeded Commander Hyland, in charge of the Fuel-Oil Testing Plant. The quick detachable-yoke coupling is retained, but the strainer is omitted and the oil passes directly into a heavy steel tube, the end of which is recessed to receive a steel plug which is chamfered, on the end which faces the tip of the burner, at an angle of about 26 degrees with a plane at right angles to the axis of the burner. The extreme end of the plug is faced off smooth to give a flat surface which corresponds in diameter with a recess in the steel tip, which in turn communicates with the outlet orifice through a small conical chamber. On the conical face of the plug four grooves are cut which are tangential to the chamber in the tip. The oil reaches the outer ends of these tangential channels by passing through a hole drilled in the center of the plug which communicates with another hole drilled at right angles to same, thus delivering the oil to an annular chamber formed by a recess machined in the side of the plug. The steel tip itself screws on to the end of the oil pipe in such a way as to provide a large chamber to receive the

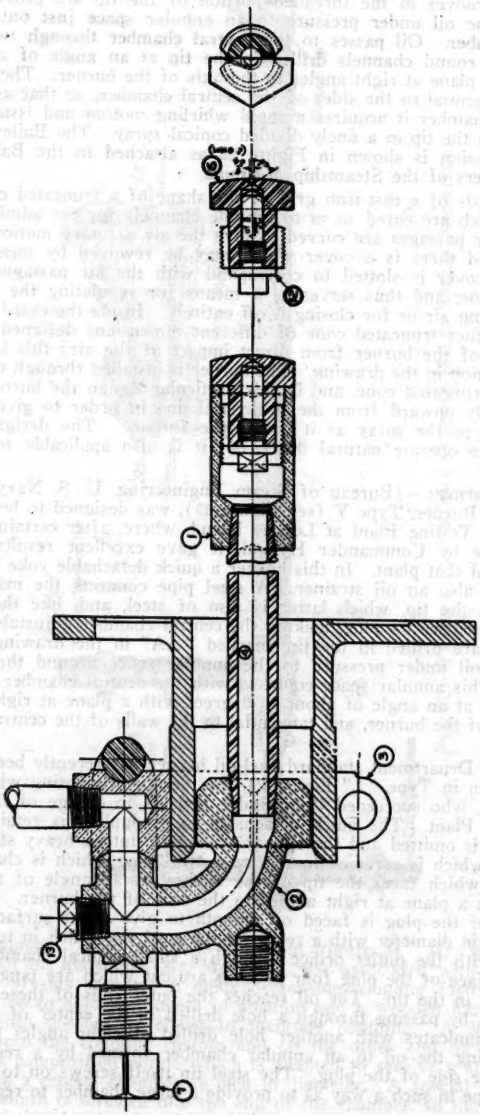


FIG. 21.—BAILEY BURNER.

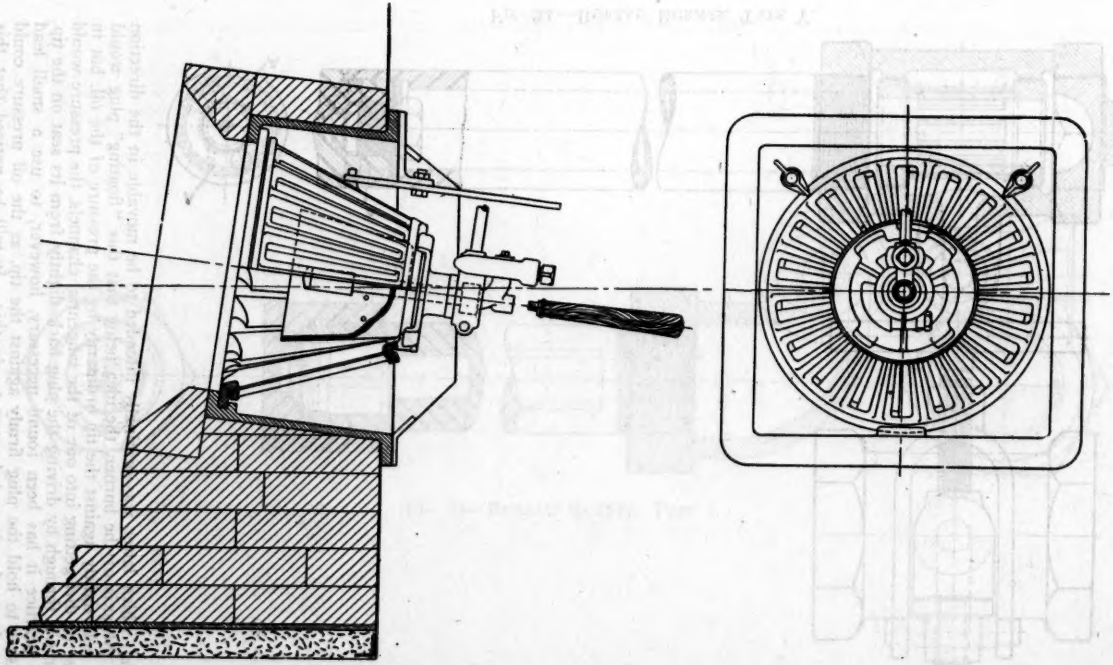


FIG. 22.—BAILEY AIR CONTROL AS FITTED TO THE BABCOCK & WILCOX BOILERS ON THE S. S. "MATSONIA."

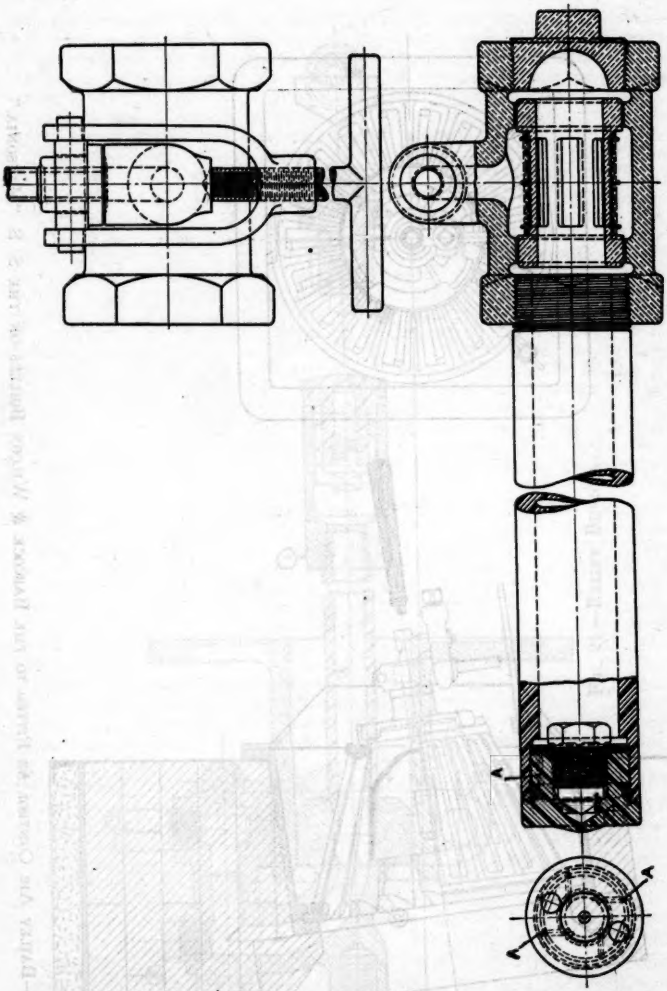


FIG. 23.—BUREAU BURNER, TYPE Y.

plug, which latter was originally intended to be movable in the direction of the axis of the burner, the idea being that this "floating" plug would be held tightly against the tip ordinarily by the pressure of the oil, but in case of dirt getting into one of the tangential channels, the pressure would force it through by driving the plug back slightly from its seat on the tip. In practice it has been found necessary, however, to use a small lead gasket to hold the plug firmly against the tip, as the oil pressure could not always be depended upon to do this. It will be noticed that this

FIG. 23.—BUREAU BURNER, TYPE Y.

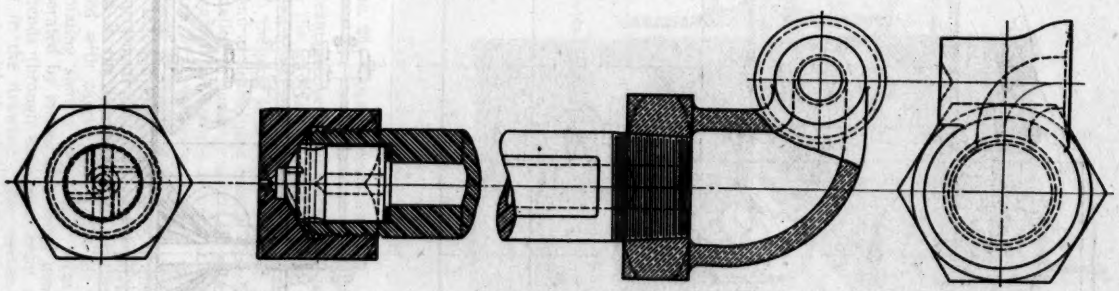


FIG. 24—BUREAU BURNER, TYPE I.

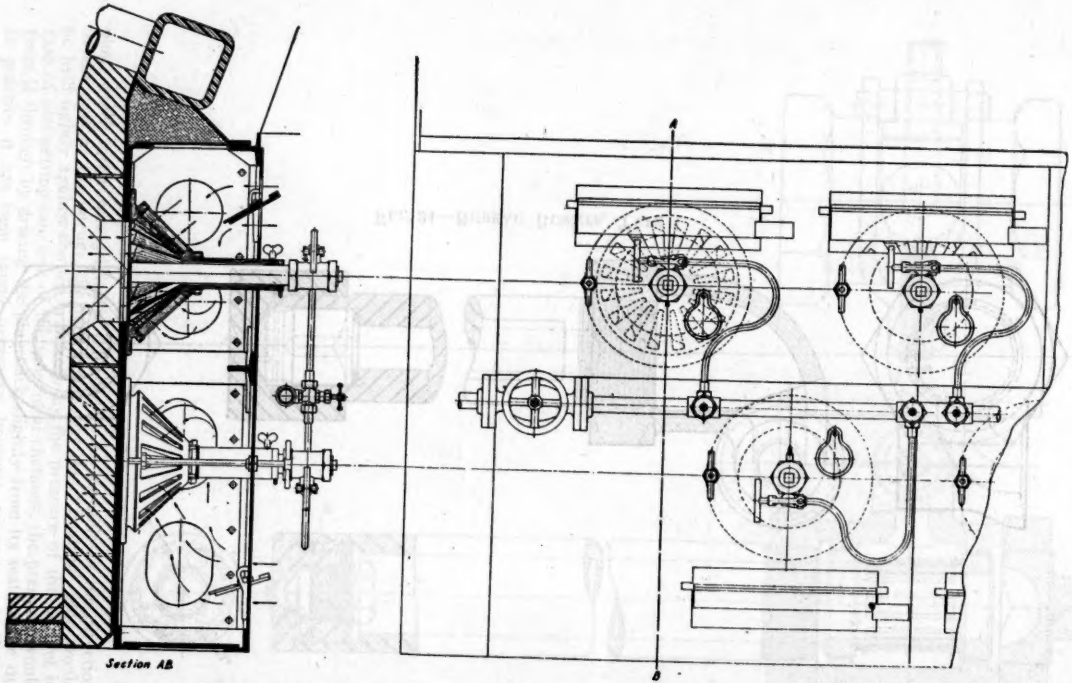


FIG. 25.—BUREAU AIR CONTROL FITTED TO BABCOCK & WILCOX BOILER WITH DOUBLE FRONT.

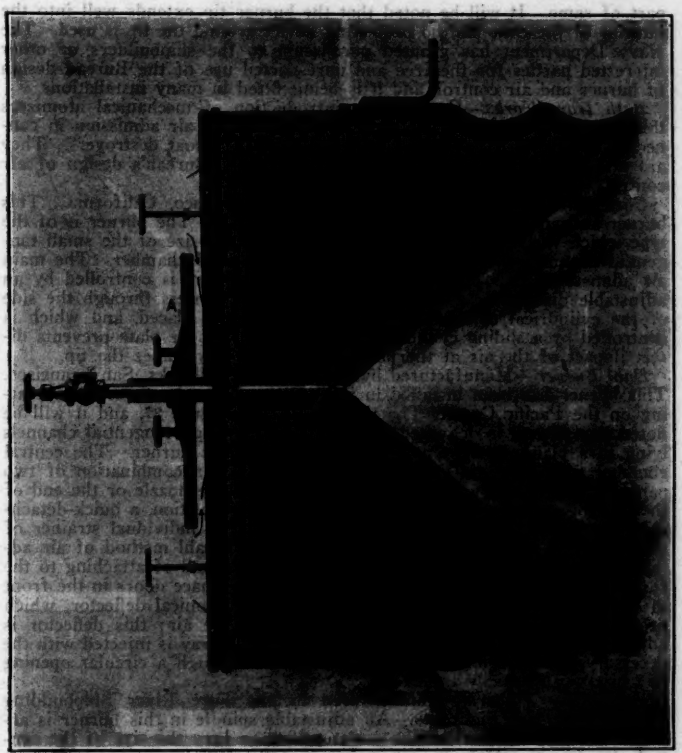


FIG. 26.—COEN BURNER AND AIR CONTROL.

burner has the advantage over the previous design in that by removal of the tip (which, by the way, is made hexagonal in shape for the reception of an ordinary wrench and does not require a special tool, as in the case of the first design) the plug is at once removable and the tangential channels are exposed and are easily and quickly cleaned. Burners of this type are now being installed in some of our large super-dreadnaughts.

The Bureau design of air control as used at the League Island Testing Plant and perfected by Commander Hyland is shown in Figure 25, as adapted to a Babcock & Wilcox boiler with double front. The air for combustion enters through suitable openings in the outer front fitted with doors which are arranged to close automatically in case of a flare-back or excess pressure in the furnace. The air then passes into a conical cast-iron grid fitted with curved blades, the air inlet to the grid being controlled by a rotating shutter of suitable form on the exterior of the same. This is operated by means of a small gear wheel connected with a shaft which extends through the outer front and is provided with a handle, as shown in the drawing. The burner is installed through a sleeve which connects with the grid casting or may be made an integral

FIG. 25.—BUREAU AIR CONTROL FITTED TO BABCOCK & WILCOX BOILER WITH DOUBLE FRONT.

part of same. It will be noted that the burner tip extends well into the interior of the cone and no protecting device around the tip is used. The Navy Department has granted permission to the shipbuilders or other interested parties for the free and unrestricted use of the Bureau design of burner and air control, and it is being fitted in many installations.

Bath Iron Works.—On the first introduction of mechanical atomizers this firm used the Normand burner and method of air admission in connection with Normand boilers installed on torpedo-boat destroyers. They are now, however, using the Bureau burner and Bureau's design of air control.

Coen Burner.—The Coen Company, San Francisco, California. This burner and air control are illustrated in Figure 26. The burner is of the type which varies the output of oil by altering the size of the small tangential channels which deliver the oil to the central chamber. The main air admission, as is clearly shown in the illustration, is controlled by an adjustable disc, while a supplementary air supply enters through the side of the cylindrical chamber in which the burner is placed, and which is controlled by a sliding cylinder. An adjustable disc or plate prevents direct impact of the air at the point where the spray leaves the tip.

Dahl Burner.—Manufactured by the Union Iron Works, San Francisco. This burner has been installed in a great many merchant vessels operating on the Pacific Coast. The tip is shown in Figure 27, and it will be noted that the oil is delivered under pressure through tangential channels lying in a plane at right angles to the axis of the burner. The central chamber and tangential channels are made up by a combination of two parts held together by a nut which screws on to the nozzle or the end of the oil delivery pipe. In fastening the burner in position, a quick-detachable coupling is used of the fixed-yoke type and an individual strainer of simple design is provided with the burner. The Dahl method of air admission is shown in Figure 28, illustrating the method of attaching to the furnace of a Scotch boiler. Air enters through furnace doors in the front of the furnace and passes around and through a conical deflector, which protects the burner tip from direct impact of the air; this deflector is adjustable in the line of axis of the burner. The spray is injected with the necessary air for combustion into the furnace through a circular opening in a brick wall suitably arranged.

Fore River Burner.—Manufactured by the Fore River Shipbuilding Corporation. See Figure 29. An adjustable spindle in this burner is arranged to throttle or close the outlet orifice or vary the size of the central chamber to which the oil is delivered through two tangential channels. The burner is provided with a quick detachable arrangement for holding it in place. The tangential channels are in a plane at right angles to the axis of the burner. This company now uses the Bureau design of air control with all their oil-burning installations.

The Moore & Scott Iron Works, San Francisco, manufacture a burner shown in Figure 30, in which it will be noticed that the oil is delivered to the chamber communicating with the discharge orifice, through oil passages cut in the sides and on the end of a plug which is adjustable in the direction of the axis by means of a spindle passing completely through the burner; a special strainer is used and the union for connecting the oil piping is fitted with a special means for detaching quickly. Figure 31 shows the method of arranging this burner for use in the furnace of a Scotch boiler and the method of admitting air for combustion.

Peabody Mechanical Burner.—The illustration, Figure 32, sufficiently explains this burner, which was recently described in a letter of inquiry as "two nuts and a slotted plate, screwed on the burner barrel." In designing this burner the attempt was made to secure simplicity and to reduce to a minimum the surface with which the whirling oil is in contact. The central hole in the washer or disc is ¼-inch diameter, and this cor-

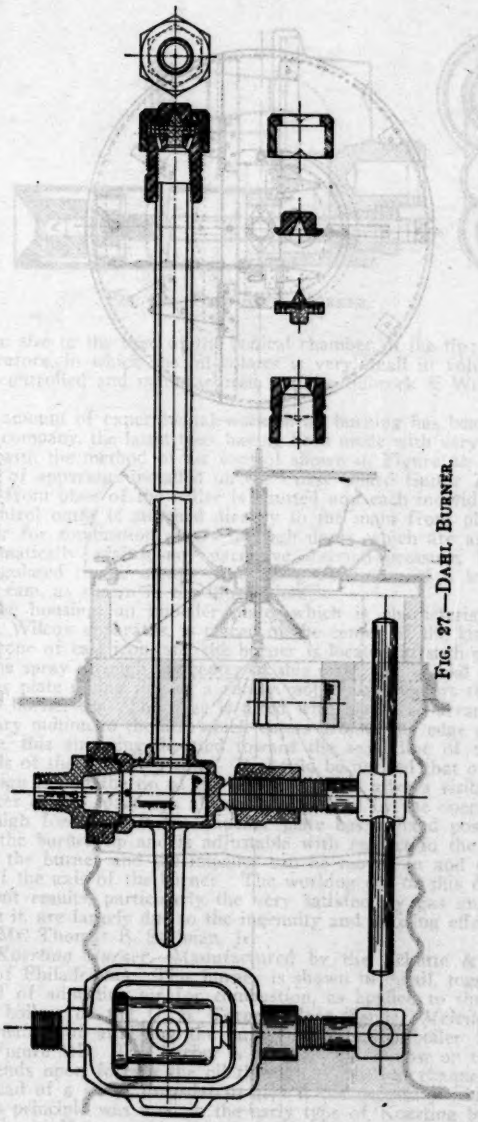


FIG. 27.—DAHL BURNER.

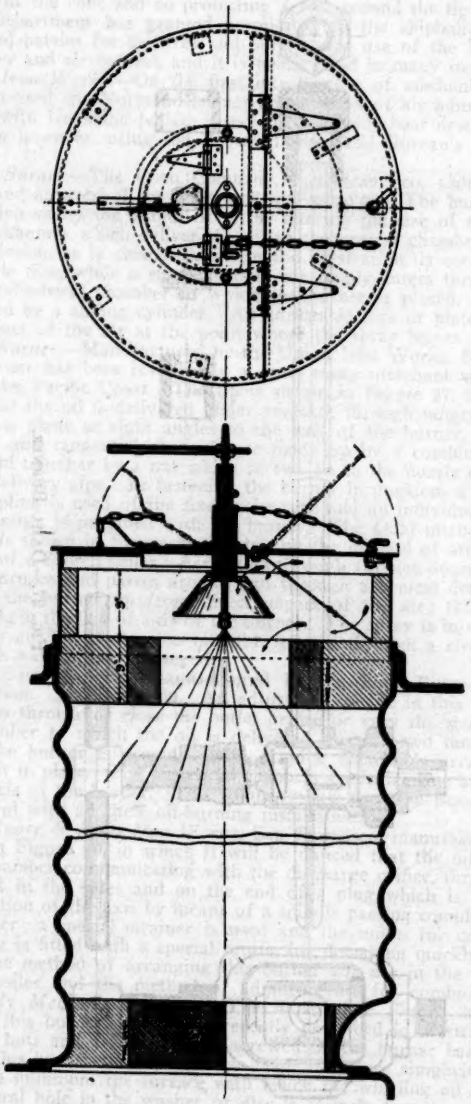


FIG. 28.—DAHL AIR CONTROL.

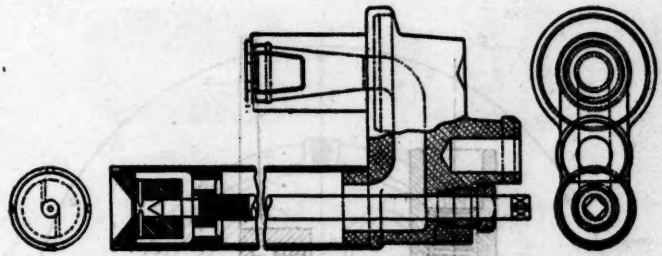


FIG. 29.—FORE RIVER BURNER.

responds in size to the base of the conical chamber in the tip; the entire space, therefore, in which the oil rotates is very small in volume. This burner is controlled and manufactured by The Babcock & Wilcox Company.

A large amount of experimental work in oil burning has been conducted by this company, the latest tests having been made with very low natural draft, with the method of air control shown in Figure 33, this being the design of apparatus installed on the Coast Guard Cutter *Tallapoosa*. The outer front plate of the boiler is omitted and each individual burner and air-control outfit is attached directly to the main front plate of the boiler. Air for combustion enters through doors which are arranged to close automatically against any excessive internal pressure, but which may be regulated in the matter of opening by means of a lever which operates a cam, as shown in the illustration.

Inside the housing, an impeller plate, which is characteristic of the Babcock & Wilcox apparatus, is placed in the center of the large end of truncated cone of cast iron, and the burner is located in such position as to inject the spray through the center of this plate; the special blading of the impeller plate giving the air a rotary motion as it enters the furnace around the burner tip. The cone is fitted with blades so arranged as to give a rotary motion to the air, which enters around the edge of the impeller plate, this air being directed toward the axial line of the burner by the walls of the truncated cone. It should be noticed that one feature of this design is that the tip of the burner itself is always visible, so that the character of the spray can always be observed by the operator. For use with high forced draft the impeller plate has a fixed position with regard to the burner tip and is adjustable with respect to the truncated cone, *i. e.*, the burner and the impeller can be moved in and out in the direction of the axis of the burner. The working out of this design and the excellent results, particularly the very satisfactory gas analyses obtained with it, are largely due to the ingenuity and untiring efforts of my colleague, Mr. Thomas B. Stillman, Jr.

Schutte-Koerting Burner.—Manufactured by the Schutte & Koerting Company of Philadelphia. This burner is shown in detail, together with the method of admitting air for combustion, as applied to the Babcock & Wilcox boilers of the U. S. Torpedo-Boat Tender *Melville*, Figure 34A. A method of attaching the burner to a Scotch-boiler furnace is shown in Figure 34B. This burner is one of the few now on the market which depends upon forcing the oil through the helical channels formed by the thread of a screw in order to give it the necessary whirling moturn. This principle was used in the early type of Koerting burner and is still retained. Very considerable designing skill has been shown in the method of attaching, arrangement of strainers, etc. The small spindle on

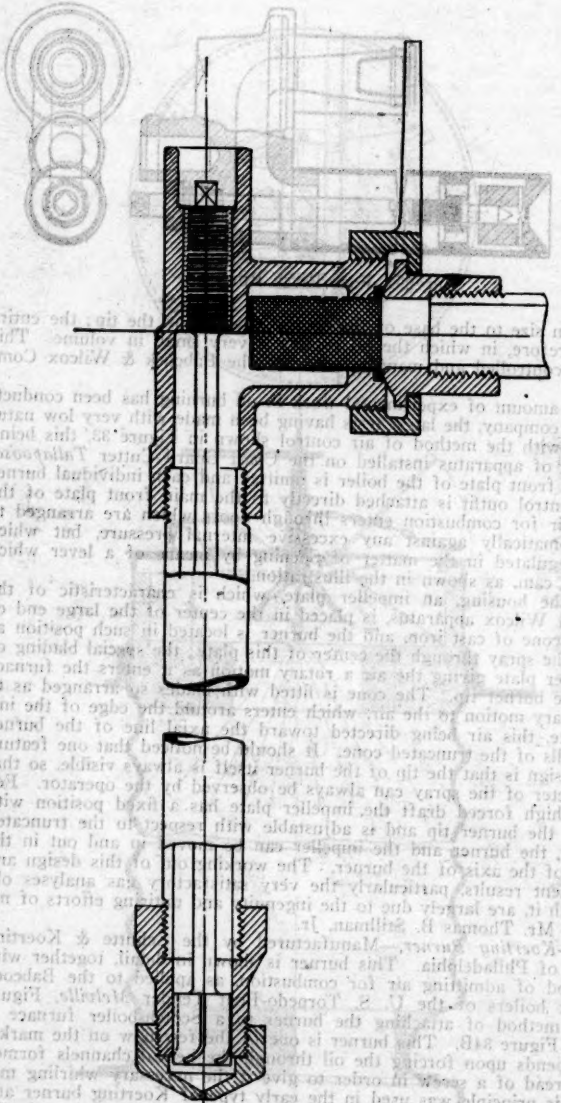


FIG. 30.—MOORE & SCOTT OIL BURNER.

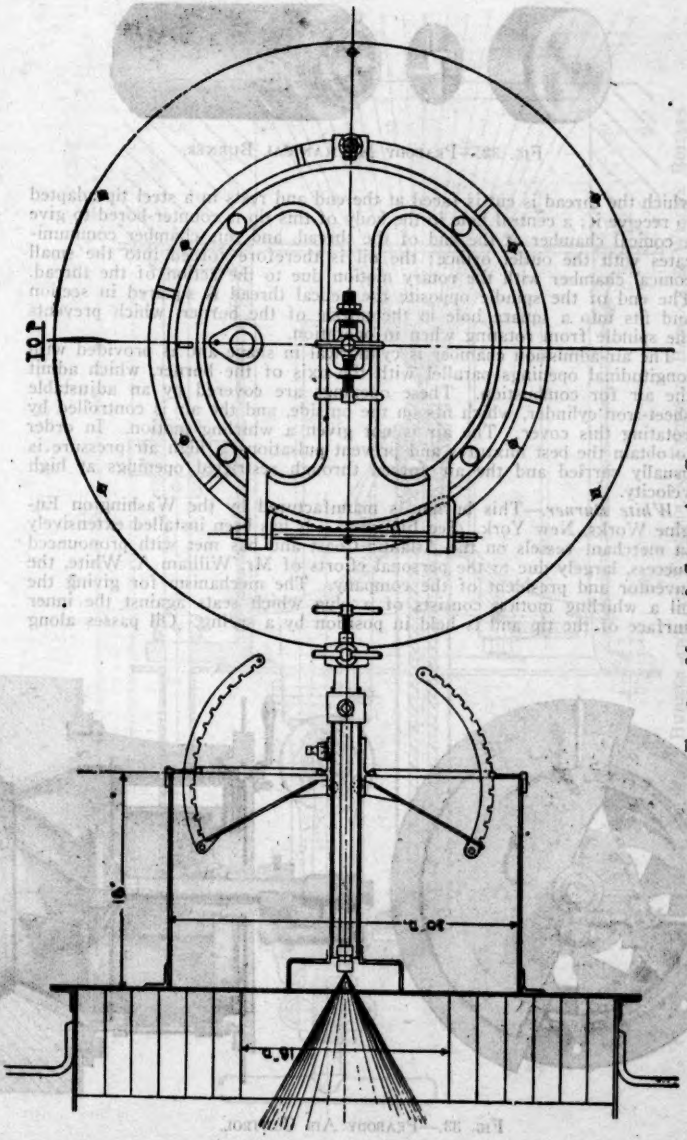


Fig. 31.—Moore & Scott Air Control.

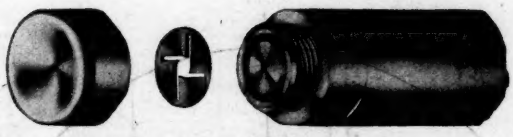


FIG. 32.—PEABODY MECHANICAL BURNER.

which the thread is cut is faced at the end and rests in a steel tip adapted to receive it; a central hole in the body of this tip is counter-bored to give a conical chamber at the end of the thread, and this chamber communicates with the outlet orifice; the oil is therefore forced into the small conical chamber with the rotary motion due to the action of the thread. The end of the spindle opposite the helical thread is squared in section and fits into a square hole in the nozzle of the burner, which prevents the spindle from rotating when in operation.

The air-admission chamber is cylindrical in shape and is provided with longitudinal openings parallel with the axis of the burner, which admit the air for combustion. These openings are covered by an adjustable sheet-iron cylinder, which fits on the outside, and the air is controlled by rotating this cover. The air is not given a whirling motion. In order to obtain the best mixtures and prevent pulsations, a high air pressure is usually carried and the air forced through restricted openings at high velocity.

White Burner.—This burner is manufactured by the Washington Engine Works, New York. See Figure 35. It has been installed extensively in merchant vessels on the Atlantic Coast and has met with pronounced success, largely due to the personal efforts of Mr. William A. White, the inventor and president of the company. The mechanism for giving the oil a whirling motion consists of a plug which seats against the inner surface of the tip and is held in position by a spring. Oil passes along

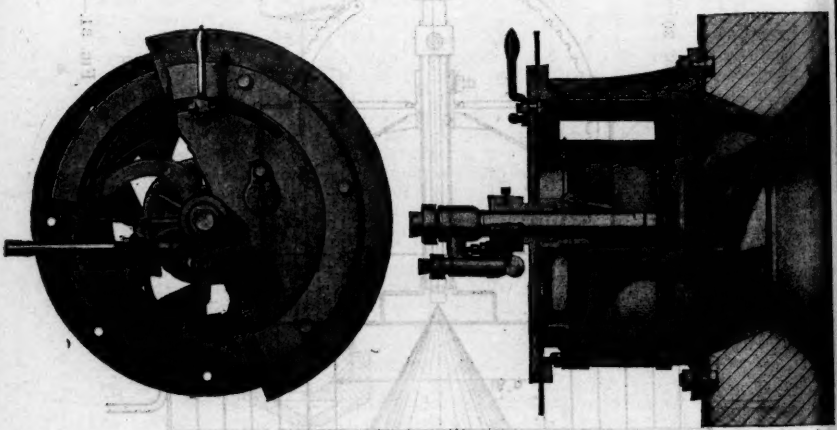


FIG. 33.—PEABODY AIR CONTROL.

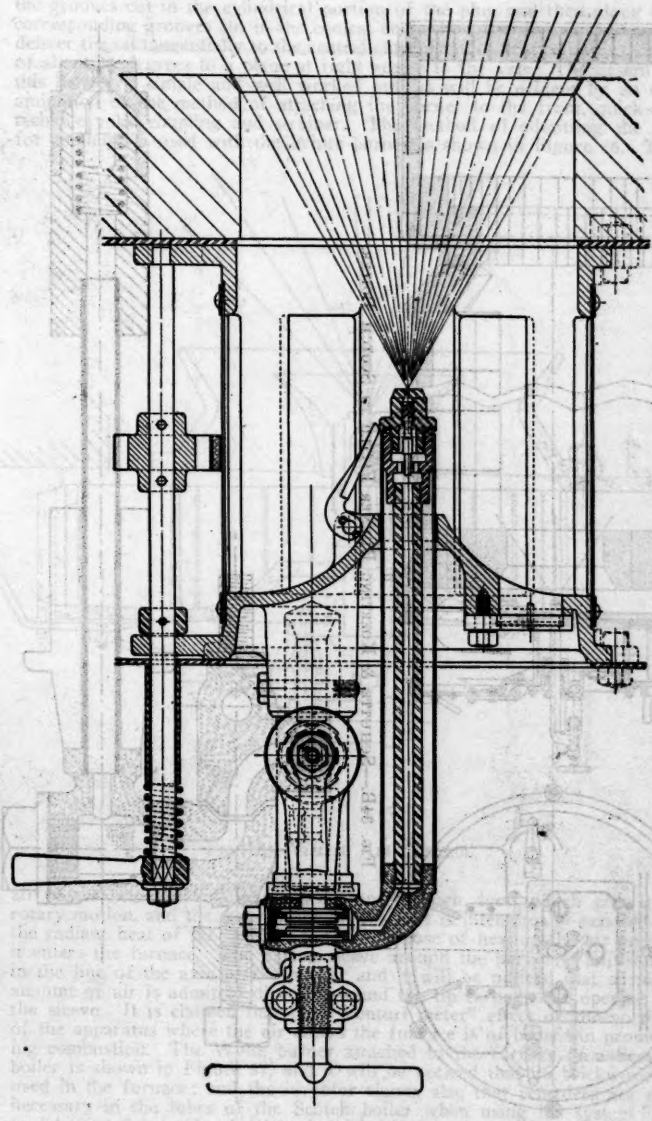


FIG. 34A.—SCHUTTE & KOERTING BURNER AND AIR CONTROL AS FITTED TO BABCOCK & WILCOX BOILERS OF THE U. S. S. "MELVILLE."

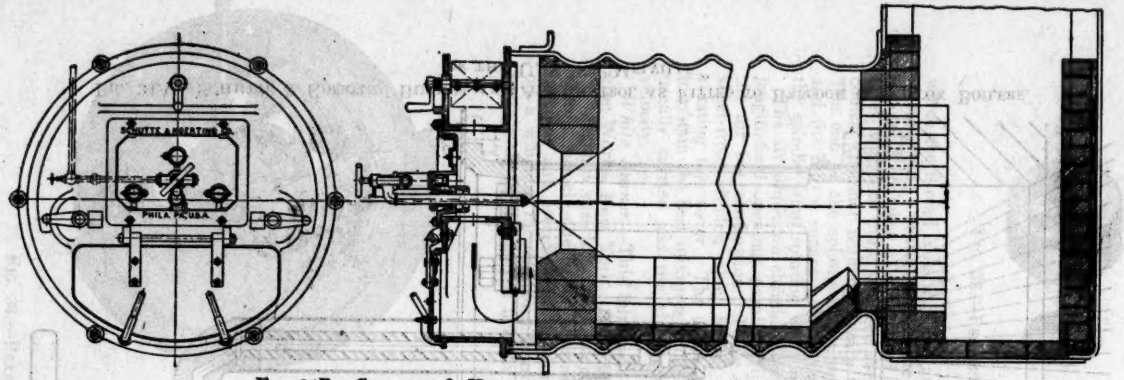


FIG. 34B.—SCHUTTE & KOERTING BURNER FITTED TO SCOTCH BOILER.

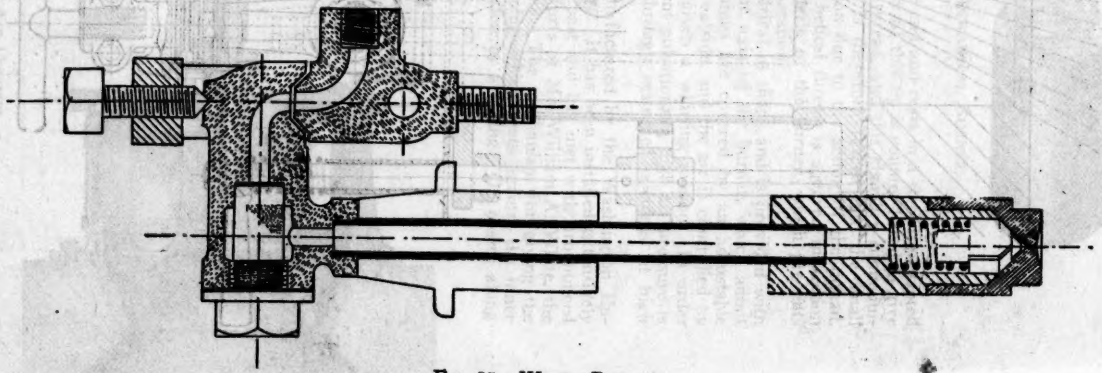


FIG. 35.—WHITE BURNER.

the grooves cut in the cylindrical portion of the plug and then along the corresponding grooves cut in the conical end, which are so arranged as to deliver the oil tangentially to the central chamber in the tip and at an angle of about 45 degrees to a plane at right angles to the axis. The design of this burner is simple and well worked out, as will be evident by an examination of the method of attaching the burner to the front, quick-detachable yoke coupling and strainer. The method of admitting the air for combustion used with the White burner is shown in Figure 36. The

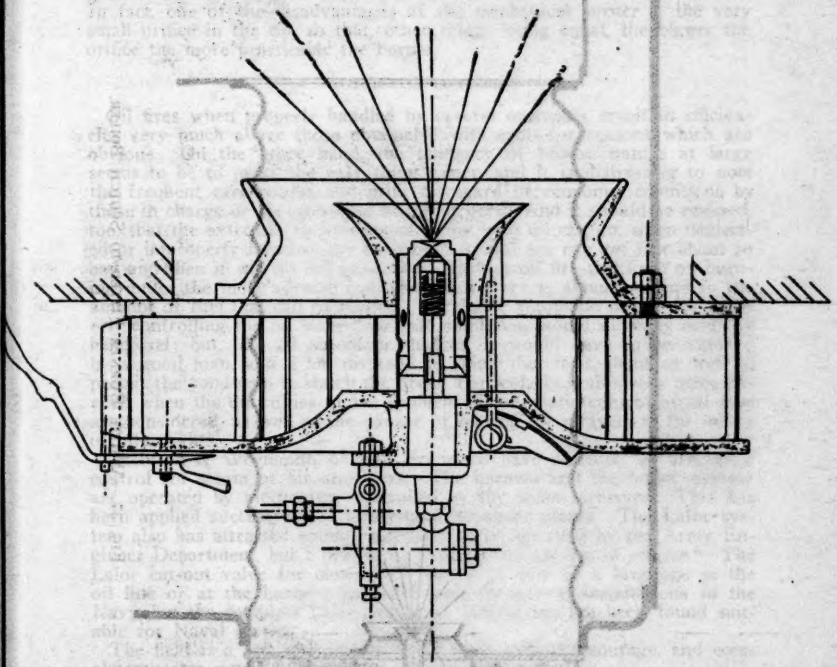


FIG. 36.—WHITE AIR CONTROL.

air passes into the hollow furnace front through ducts which give it a rotary motion, and the metal work of this part is intentionally exposed to the radiant heat of the furnace for the purpose of heating the air before it enters the furnace. The flaring sleeve around the burner is adjustable in the line of the axis of the burner and it will be noticed that a small amount of air is admitted directly around the tip through the opening in the sleeve. It is claimed that the "Venturi meter" effect of the portion of the apparatus where the air enters the furnace is of benefit in promoting combustion. The White burner attached to the furnace of a Scotch boiler is shown in Figure 37, and it will be noticed that no brickwork is used in the furnace; and the inventor claims also that retarders are not necessary in the tubes of the Scotch boiler when using his system. It may be noted here that brickwork in the furnace of Scotch boilers using

FIG. 35.—WHITE BURNER.

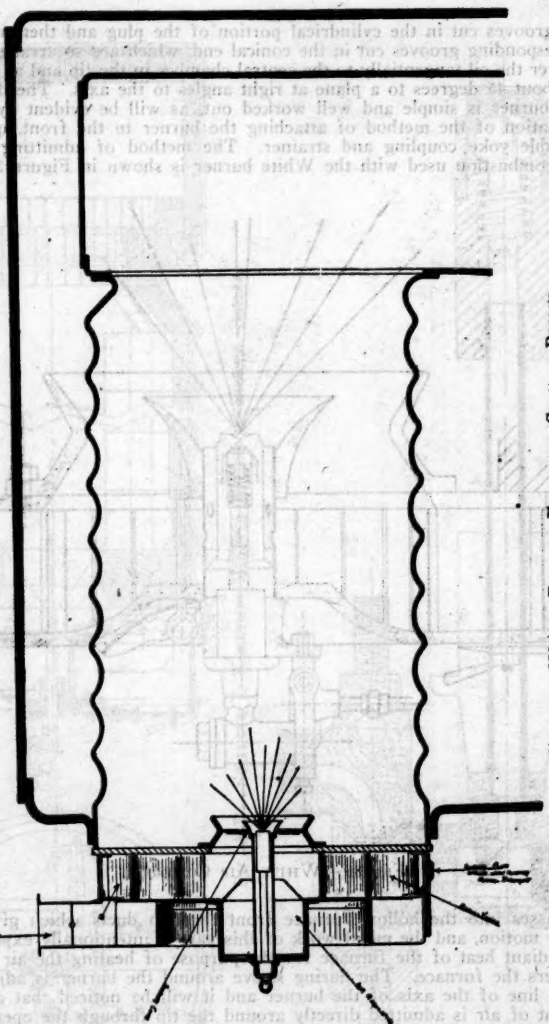


FIG. 37.—WHITE BURNER FITTED TO SCOTCH BOILER.

oil fuel is usually installed because it is supposed to give better economy; the same thing may be said of retarders in the boiler tubes.

An inspection of the various burner designs described above will indicate a preponderance of the type in which the oil is delivered not only tangentially to the walls of the central chamber, but at an angle to a

plane at right angles with the burner axis. The prevalence of this idea suggests the possibility of its possessing some inherent advantage. We have not been able to find this in our experiments, and we adhere to the flat-disc design delivering oil tangentially to the central chamber in a plane at right angles to the axis of the burner: First, because it is simpler; second, because we believe it gives a finer spray, which is an advantage rather than otherwise; and third, because the net effect of the angular delivery is to increase the output of the burner for a particular size of orifice and at given oil pressures and temperatures. We prefer, if greater burner output is desired, to increase the diameter of the orifice. In fact, one of the disadvantages of the mechanical burner is the very small orifice in the tip, so that, other things being equal, the bigger the orifice the more practicable the burner.

AUTOMATIC CONTROL.

Oil fires when properly handled by careful operators result in efficiencies very much above those obtainable with coal, for reasons which are obvious. On the other hand, the tendency of human nature at large seems to be to make the easy thing easier, and it is distressing to note the frequent carelessness and utter disregard of economic conditions by those in charge of the operation of oil burners. And it should be realized, too, that the extremes to which poor firing with oil can go, when neglected or improperly handled, are limitless. A coal fire can get just about so bad and then it will go out altogether. But an oil fire will keep on burning under the most adverse conditions and there is almost no end to the amount of fuel that can be wasted. A reliable automatic device for properly controlling the oil burner and air admission would in many cases be beneficial; but, like all automatic devices, it would have to be watched by a good man, and I am disposed to think that it is about as well to permit the *good* man to watch the fires. Particularly is this view strengthened when the difficulties of the problem of automatic control of oil fires are considered, as well as the danger of leaving oil sprayers at the mercy of pilot lights.

Atchison & Weymouth of San Francisco have patented an automatic control for steam or air atomizers. The burners and the boiler damper are operated by mechanism controlled by the steam pressure. This has been applied successfully, I understand, to shore plants. The Lalor system also has attracted enough attention to be specified by the Army Engineer Department, but I believe no installations are yet in service.* The Lalor cut-out valve for closing off the oil in case of a breakage in the oil line or at the burners has been used in several installations in the Navy, but the complete Lalor automatic control has not been found suitable for Naval service.

The field is a fair one for inventors with sufficient courage, and complete success would be welcome.

FORCED-DRAFT BLOWERS.

While excellent natural-draft results may be obtained with oil—both with steam and mechanical atomizers—the high boiler capacities which may be developed with this fuel require high forced draft.

For maximum conditions, the closed fireroom is essential and is employed entirely in destroyer and other high-speed vessels. Electric or turbine-driven high-speed fans are used and no difficulty is experienced in obtaining 6 inches and even 8 inches of air pressure measured by water column.

Where high boiler capacity is not needed, but where natural-draft con-

*Since this paper was written the U. S. Army Dredge *Comstock*, fitted with the Lalor system, has been placed in commission after successful trials.

ditions are not quite sufficient, the burners and air-controlling devices may be housed in, and air under moderate pressure delivered into this casing, either by individual fans or by ducts. Figure 38 shows, for illustration, an arrangement of this kind used for Scotch boilers by Mr. White. It is also applicable with slight changes to water-tube boilers. The Babcock & Wilcox Company have employed this method of draft with satisfactory results.

The standard Howden heated-air system, which is so useful for Scotch-boiler installations, is easily applied to use with oil fuel. Also owing to the relatively low uptake temperatures with oil as compared with coal, the so-called "induced-draft system" is especially suitable—particularly with boilers similar to the B. & W., in which the gases leave the boiler at temperatures so low as to make the use of air heaters or economizers in the uptake hardly of sufficient value to cover the cost of installation. Induced draft has all the convenience of natural draft in the matter of handling the burners.

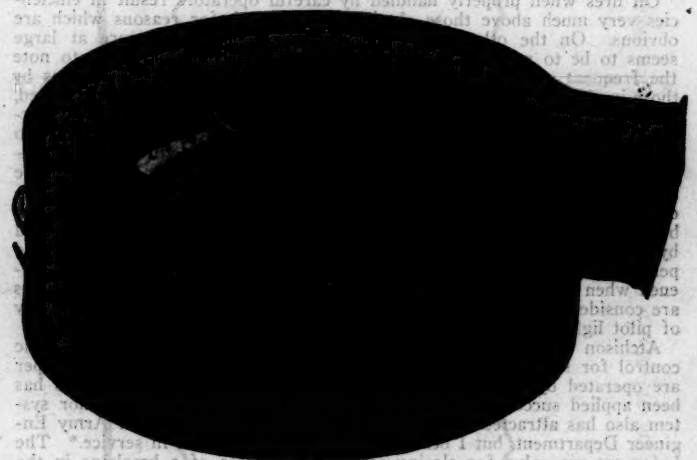


FIG. 38.—WHITE FORCED-DRAFT HOUSING FOR SCOTCH-BOILER FURNACE.

The "pressure blowers" for use with air atomizers requiring 6 to 8 *ounces* pressure, once a considerable source of trouble, have passed away as burners of the mechanical type have been more widely introduced.

FURNACE DESIGN.

In many respects the water-tube-boiler furnace is better adapted for oil burning than the Scotch-boiler furnace; thus the larger amount of incandescent brickwork is an aid to combustion and the size and form of the furnace may be proportioned to still further promote the burning of the oil.

This is not to say that excellent results are not obtained with Scotch boilers using oil. This is a matter of common record, especially when retarders are used and the boilers operated with Howden draft, which saves heat not absorbed by the boiler and returns it to the furnace. In this connection it is worthy of remark that methods of heating air for combustion directly from the furnace itself have no value from the point

of thermal efficiency, except possibly in cases where very small or overcrowded furnaces make it desirable to promote the rapidity of combustion, when the heated air may be of some slight advantage. It is of course true that heating the air by bringing it in contact with side casing or boiler-front plates which are insufficiently lagged may save some heat which would otherwise go to waste; but deliberately reducing the lagging for the purpose of heating the air is only "robbing Peter to pay Paul," and further, it results in undue losses through radiation during "stand-by" periods. The best practice is to properly protect the boiler against radiation losses and avoid complications installed for the purpose of heating the air, unless the source of heat is from the waste gases.

It has long been recognized that the type of burner, while important, is of less significance than the size and general design of the furnace. In

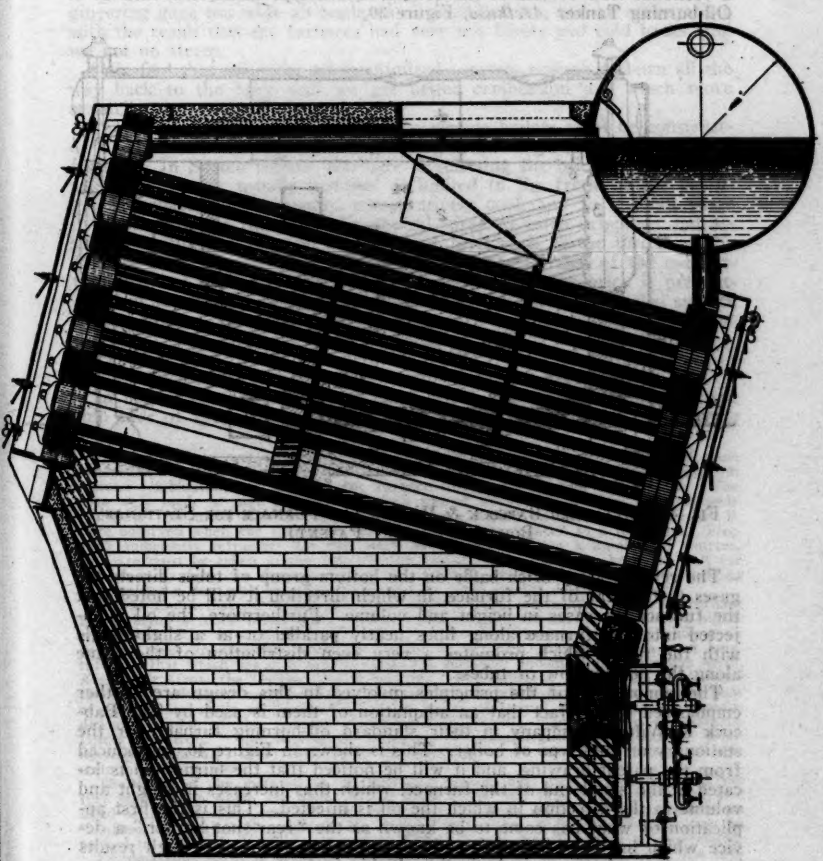


FIG. 39.—FURNACE OF BABCOCK & WILCOX MARINE BOILER.

those cases, now becoming rare, where the oil is atomized to the point of giving "flameless combustion," furnace design does not require so much care; but where a flame exists, it must be prevented from localizing on the boiler surfaces and the gases must be kept highly heated and given time and space in which to burn as completely as possible before being brought into contact with the boiler. Air admission and control are of prime importance, and the round-flame mechanical atomizer particularly requires special means for mixing thoroughly and evenly the minimum amount of air with the oil spray; also, as the gases expand and burn they require more room.

The best furnace conditions for burning oil are so well represented in the furnace of the Babcock & Wilcox marine boiler that I give herewith a sectional view of one of the boilers of this type installed in the U. S. Oil-burning Tanker *Arethusa*, Figure 39.

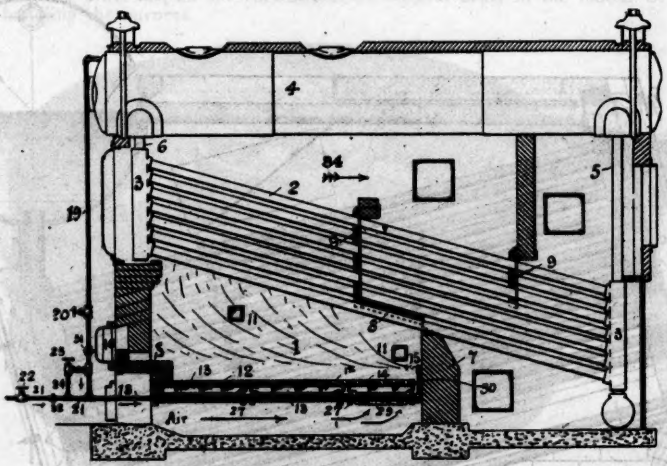


FIG. 40.—STANDARD BABCOCK & WILCOX OIL FURNACE FOR STATIONARY BOILERS (PEABODY PATENT).

The reverberatory brick baffle on the bottom group of tubes directs the gases to the rear of the furnace, in which direction it will be noted that the furnace increases in height and volume. Furthermore, the oil is injected into the furnace along lines nearly parallel or at a slight angle with the tubes, which promotes a very even distribution of the flame along the bottom row of tubes.

The importance of the principles involved in this design are further emphasized by the fact that an adaptation of them is used by The Babcock & Wilcox Company in their standard oil-burning furnace for the stationary or land-type of boiler. This is shown in Figure 40, reproduced from the patent drawing, and it will be noticed that the burner tip is located at the small end of the furnace, which thus increases in height and volume in the direction in which the oil is injected. This is the first application of what has come to be known as the "rear-shot burner," a device which has been imitated many times owing to the very high results in capacity and economy obtained with this furnace arrangement.

Mr. Charles P. Wetherbee, Vice-President of the Bath Iron Works,

makes a most interesting point, indicating that in furnaces of special forms, such as that in the Normand boiler, the degree to which the oil is atomized has a marked effect on the distribution of the gases, and that the finest atomization is not desirable. This apparent anomaly has been noticed by others operating this general type of boiler and seems to be an established fact.

Mr. Wetherbee writes:

"We are using the Bureau of Steam Engineering standard burners, but our Chief Engine Draftsman, Mr. Bimson, has made a lot of experiments with them and has obtained curves for varying the proportions of the tips so that we can get any desired angle of oil cone, fineness of oil spray and quantity of output.

"We found that the exact figures given by the Bureau of Steam Engineering gave too wide an angle of oil cone and too fine an atomization, with the result that the furnaces had very hot fronts and cold backs, and we got no steam.

"We find that when the oil is atomized coarsely enough to burn all the way back to the back wall we get better combustion and much more steam."

The furnace brickwork in water-tube marine boilers must be constructed of the best material obtainable, owing to the high temperature in the furnace. In Scotch boilers, less care in selecting the brick is permissible, as the brickwork usually installed is limited to the front of the corrugated furnace, which remains comparatively cool, and to a small patch of flooring in the furnace under the oil spray to catch drippings and assist in igniting the oil, and to a ring of brickwork at the throat of the furnace at the combustion chamber end, and to the back of the combustion chamber itself. At the three points last named the brick is prevented from becoming excessively hot by contact with the water-cooled surface of the boiler. The water-tube-boiler furnace has no such protection for the bricks, the brickwork being a protection for the casing. Thus, these brick must stand the high temperature of the furnace of this character of boiler, which may reach 2,800 degrees to over 3,000 degrees F.*

In boilers of the "destroyer" class, which are built very light, strong thin tiles of special shape are used and bolted to the casing. The brick

*Since the above was written The Babcock & Wilcox Company has completed some exhaustive experiments with oil fuel, made for the purpose of thoroughly testing out various combinations of material for furnace linings for marine boiler work. The tests were made at high capacity and each was of 36 hours' duration, to thoroughly "saturate" the material with heat. Furnace temperatures exceeding 3,200 degrees F. were observed when the excess air for combustion was reduced to a minimum. Fire-brick sufficiently refractory for this work are obtainable from a number of sources, but care must be taken in the case of tiles bolted to the casing to keep the bolt far enough away from the furnace side of the brick to prevent iron oxide from forming and making a flux with the silica of the brick. This quickly destroys the wall.

It was found that pulverized fire brick made a good intermediate layer in furnace floors, being a much better heat insulator than the solid brick, and of course highly refractory. The most satisfactory insulating material, however, and one sufficiently light to make an excellent substitute for the 85 per cent. magnesia block used heretofore is that which has as a basis a substance variously known as diatomaceous earth, *Kieselguhr* (from the German words meaning "flint-sediment"), Sil-O-Cel, and sometimes as "infusorial earth"—though the latter term refers more particularly to beds of the minute shells of "infusoria," a low order of animal life, while diatomaceous deposits consist of the remains of infinitesimal aquatic plants known as diatoms. Under the title, "The Kieselguhr Industry" ("Metallurgical and Chemical Engineering," February, 1914), Mr. Percy A. Boeck gives an interesting account of this material and its uses.

The value of the material as an insulator against heat lies in the fact that the tiny plant shells which are about 90 per cent. silica, and thus highly refractory, are filled with minute air cells or voids in almost countless numbers. In an article on "Infusorial Earth," Mr. Samuel H. Dolbear states that 40,000,000 diatoms may be packed in a cubic inch. The minuteness of the air cells may therefore be appreciated.

Diatomaceous earth is prepared for use as an insulator in various ways, one convenient form being that known as Nonpareil High-Pressure Block, made by the Armstrong Cork & Insulation Co., in which asbestos fiber and some lime as a bonding material are used in combination with the earth.

are usually cored out to still further reduce weight. It is preferable, where the nature of the service permits of greater machinery weights, to use regular 9-inch fire brick and make side and rear walls at least 9 inches in thickness. In such walls, bolts are usually not required. In any case these bricks should be backed by 2 inches to 3 inches of non-conducting material between the brick and the casing plate. Magnesia is frequently used for this purpose, but it is very unsatisfactory owing to its shrinkage when heated. We are now looking for an acceptable substitute.

In laying up brick walls and flooring of oil furnaces provision should be made for expansion, but it is worth noting in this connection that there is a great difference in the coefficient of expansion of fire brick. It is possible to secure highly refractory brick and tiles made of material which expands but slightly, not over 1-16 inch in 9 inches.

The Babcock & Wilcox Company uses a light wash for making joints, composed of 15 parts (by weight) of fire clay, 5 parts of carborundum sand, and 1 part silicate of soda. The special high temperature cements on the market are a needless expense for new work, but are very effective for repairs, where they find a special field of usefulness.

It is a good idea to throw a few old glass bottles into the furnace to make a glaze on the bottom surface and fill the cracks.

FURNACE VOLUME.

In the burning of oil, "furnace volume" has the same significance that "grate surface" possesses in coal-burning installations. Strictly speaking, "effective furnace volume," or that actually occupied by the burning gases, is the volume which should be considered. This is somewhat indeterminate, however, and the proportion of the full volume actually utilized varies in different types of boilers. It is customary, therefore, to base calculations on the total volume of the combustion chamber, making an allowance where data are available for special furnace designs in which more or less of the total volume is utilized. In the Scotch-boiler furnace, little attention is paid to volume: first, because the boilers are not forced to the same extent as are water-tube boilers, and, second, because usually one burner is installed per furnace and the proportions are more or less left to take care of themselves—large-diameter furnaces generally being preferred, especially for forced draft.

But in water-tube boilers the conditions are different. Almost without exception the burners all discharge into a common combustion chamber, and conditions are at once encountered which do not enter into the problem of the "one-burner-one-furnace" arrangement of the Scotch boiler. Thus, there may be interference between the flames from adjacent burners, and undoubtedly eddies of gas occur in the furnace which affect air admission and control, although not wholly indicated by the draft gage. For instance, in a furnace fitted with, say, four burners, properly spaced and provided with proper means for air control, each burner being surrounded by a fixed area for air admission, and having a furnace volume equivalent to, say, 60 cubic feet per burner and operating at a fixed draft of, say, ½ inch at the damper, a certain maximum boiler capacity is obtainable when operating all four burners. This cannot be increased 25 per cent. by installing a fifth burner of the same size and with like air opening. In fact, under the particular conditions named, while there will be some increase, the actual gain in boiler capacity will be very little, although the burner oil-atomizing capacity and the area for the intake of air for combustion have been increased 25 per cent. This is because the oil which can be burned per cubic foot of furnace volume has a certain limit for a given draft and cannot be increased beyond that limit by the further multiplication of burners, even when accompanied by increased opening in the boiler front for air admission. The draft gage does not explain this, as the draft is kept constant at the damper and the furnace

draft will be reduced but slightly on the firing up of the fifth burner. On the other hand, if three burners are installed instead of four, keeping the size the same and the air openings the same per burner, the boiler capacity obtainable will be very much more than three-quarters of that previously obtained with the 4-burner equipment; for here each burner has a furnace volume allotted to it of 80 cubic feet instead of 60, and it will be found that the oil which can be burned per burner will be materially increased and there will be a tendency to approach the same rate of combustion of oil per cubic foot of furnace as before. Thus, the analogy between furnace volume and great surface will be obvious, though the size and number of burners and the air admission area are qualifying factors.

An interesting point we have noticed in our experiments is the fact that the actual limit in the rate of combustion of oil per cubic foot of furnace is apparently a matter of heat units rather than pounds of oil; or to put it another way, the boiler capacity obtainable under given conditions of burner equipment, furnace volume and draft, seems to be more or less independent of the quality of oil, *i. e.*, more oil of poor quality can be burned without smoke than of the richer oil. The total number of heat units evolved, however, in a given time is approximately constant. The net result is that just as high boiler capacity can be obtained with a given draft with good oil and bad oil. I am not ready to say that this will not have decided limitations, but the indication is that larger furnaces will not be required for poor oil.

AIR FOR COMBUSTION—UPTAKE AREA.

The air required for complete combustion varies with the composition of the oil. Approximately, however, it may be considered about 14 pounds of air per pound of oil or about 183 cubic feet at 60 degrees F.

The nature of the fuel and methods of burning it permit the excess air required for complete combustion in the furnace to be reduced very greatly—tests having shown less than 10 per cent. This means that the air actually required per pound of oil under the best conditions will equal about 200 cubic feet at 60 degrees F. A liberal allowance over this figure should be made when figuring sizes of blowers, air ducts, etc., as test conditions cannot be maintained in practice.

While it will be evident that uptake and funnel areas can be made smaller for oil than for coal, it must be remembered that for each pound of oil burned about one pound of steam is formed in the furnace due to the combustion of the hydrogen. This passes away through the uptakes and funnel as superheated steam.

The United States Navy has fixed the areas of funnels in recent installations as 1 square foot for each 300 pounds of oil burned per hour. This proportion has been reduced to 1 square foot for each 375 pounds of oil burned per hour in "destroyers," which have short uptakes and funnels. These areas, while adequate for naval vessels which operate at maximum power only under forced-draft conditions, should not be taken as a criterion for merchant service. A safe rule would provide 1 square foot cross sectional area of funnels for each 200 pounds of the maximum amount of oil burned per hour.

NUMBER OF BURNERS PER BOILER.

The less the volume of combustion space provided per burner, the less the ultimate capacity per burner in pounds of oil burned (or as elsewhere noted, B.t.u. evolved), under fixed conditions of draft. This falling off in maximum individual burner capacity, as the number of burners per furnace is increased, is in less proportion, however, than the increase in the number of burners, assuming that the total furnace volume and the draft remain constant, so that up to a certain point the ultimate boiler capacity obtained with a fixed draft is increased by using a larger num-

ber of smaller size burners. The increments grow less and less, however, as the limit is approached in the rate at which the oil can be burned. This limit increases with the draft, and for approximate values, with a draft at the damper equal to ¼ inch, the limit may be placed at about 5 pounds of oil per cubic foot of furname volume per hour; and with forced draft equal to five inches of water, at about 15 pounds of oil per cubic foot of furnace volume per hour, assuming the oil to contain about 19,000 B.t.u. per pound. At any rate, these figures are a little better than anything I know of having been produced as yet.

It has for some years been customary in torpedo-boat destroyers to use burners which will individually handle upwards of 500 pounds of oil per hour, where high capacity under forced draft is mandatory and where maximum economy is not a paramount requirement. Burners of this size have been satisfactory for this service.

A few years ago we fixed upon about 350 pounds of oil per burner per hour as the maximum individual burner output it was desirable to use, for the reason that the same intimate mixture of air with the oil spray could not be secured with the larger sizes. Thus the smaller size burners gave better efficiency. The *Tallapoosa* tests, however, show that excellent gas analyses may be obtained when delivering upwards of 600 pounds of oil per burner per hour, and Messrs. Babcock & Wilcox, Limited, of England, with their own design of air control and a modification of the Peabody burner, have recently made some very interesting tests, burning 880 pounds of oil per burner per hour. The boiler efficiency was in this case 73.4 per cent. at the rate of evaporation of 16.15 pounds of water per hour per square foot of heating surface from and at 212 degrees F. We are continuing experiments at the Bayonne plant of The Babcock & Wilcox Company, using air control similar to the *Tallapoosa* design, but of larger area, and with burner tips size No. 32 (drill number); and Mr. Stillman has recently succeeded in atomizing well above one thousand pounds of oil per burner per hour, with corresponding gas analyses showing more than 14 per cent. CO_2, with no CO.

With these figures before us it is evident that the size of burner for future installations will be increased and the number of burners per boiler will be reduced for equivalent capacities.

With a large number of small burners a variable load is carried successfully and easily by shutting off and lighting up burners to meet the heavier fluctuation, while the oil pressure and temperature provide very satisfactory regulation for slight variations. It is well known that the amount of oil (pounds per hour) sprayed by a mechanical atomizer varies directly as the pressure and inversely as the temperature. Below a certain "critical temperature" heating the oil increases the burner output, but ordinary working temperatures are usually above this point, so that heating the oil usually reduces the burner capacity.

The effects of pressure and temperature on burner capacity are shown in the accompanying chart, Figure 41. The size or number of the burner corresponds to the size of drill used in drilling the orifice in the tip.

Should a few large-capacity burners be installed, the flexibility to meet all load conditions decreases to some extent when using burners of the now popular fixed-orifice type. Possibly this may lead to wider use of burners of the adjustable or regulating type. A number of these are on the market, including the clever inventions of Mr. Thornycroft, one of which was used in one of our early destroyers. We have, ourselves, not found it necessary or desirable to use adjustable burners.

Mr. D. J. Irish has also proposed a burner which he calls the "High-low" type—that is, there is an adjustment which renders the burner capable either of delivering a high capacity or a low capacity. One adjustment only eliminates to a considerable extent the liability of faulty setting of the completely adjustable burner, which in the hands of unskilled operators is one of the objections to the latter type.

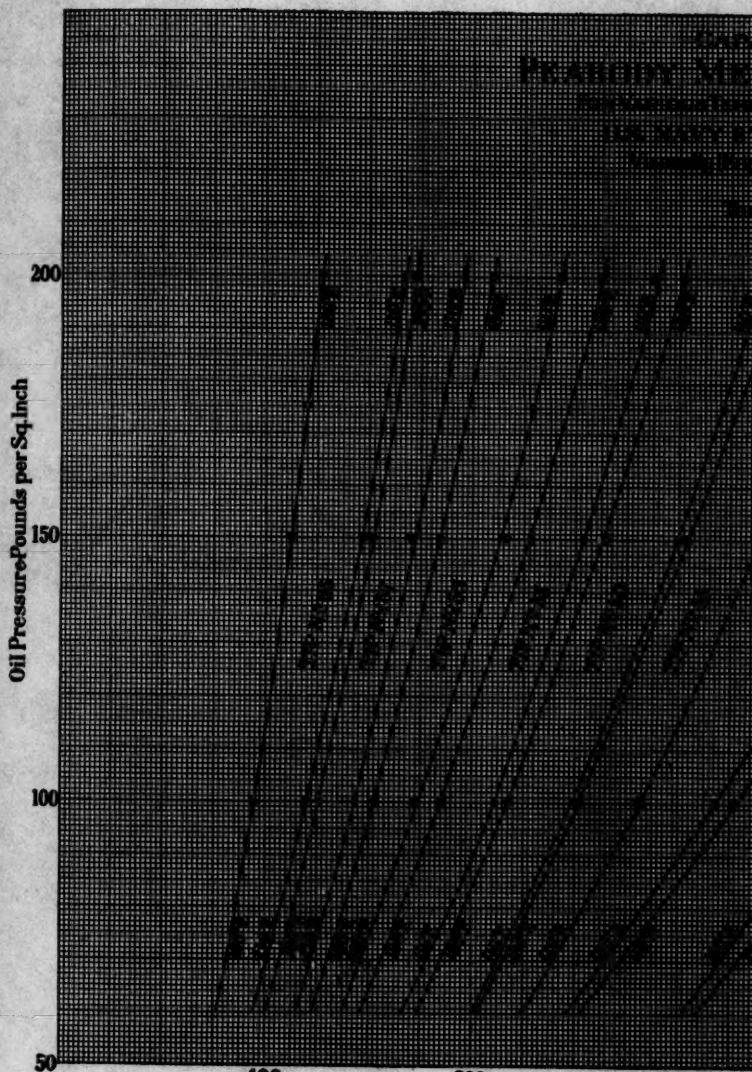
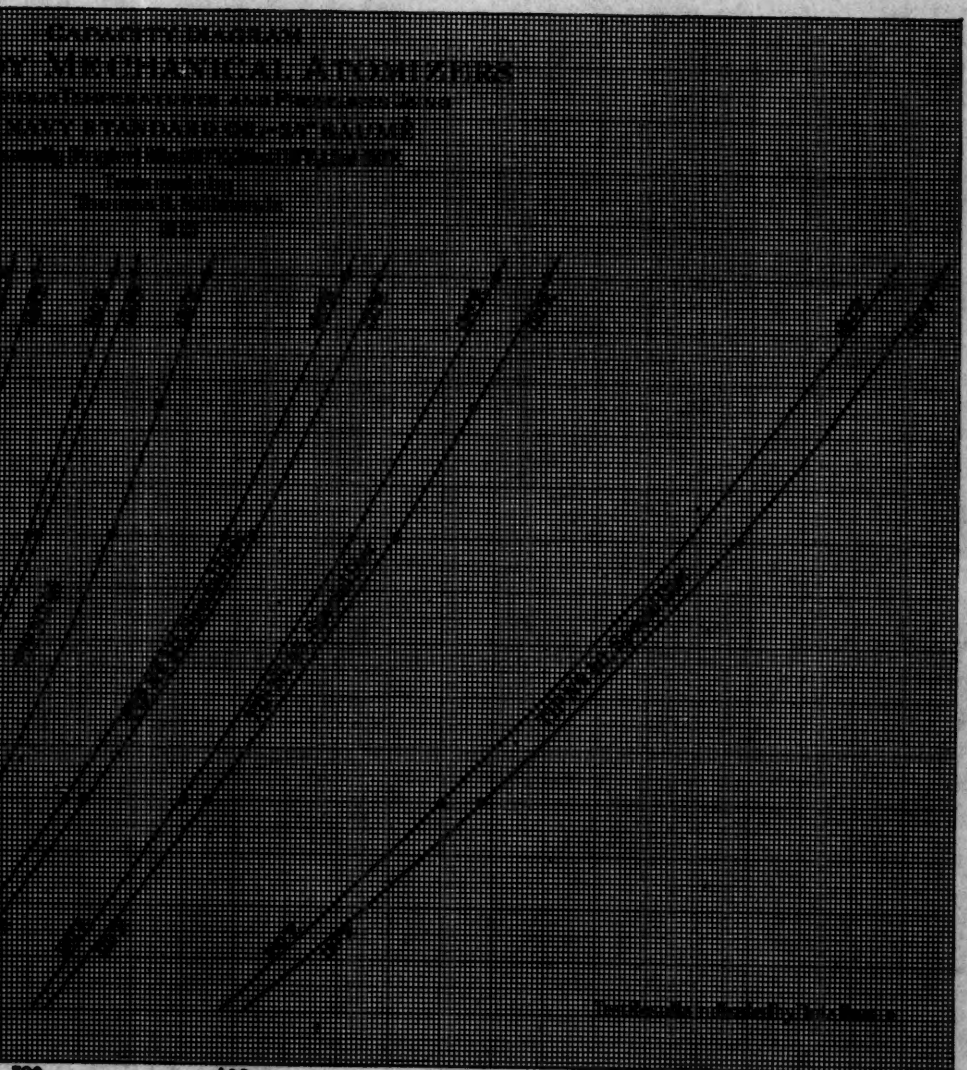


FIG. 41.—CAPACITY



CAPACITY DIAGRAM. PEABODY BURNER.

The "High-low" burner has a special field also in those cases where the plant may operate alternately at forced or natural draft. It will also be useful for port use for Naval vessels, where it is now customary to use special tips, about half the standard size.

With the quick-detachable couplings now generally used, it is, on the other hand, an easy matter to substitute a large burner for a small one and vice versa.

GETTING UP STEAM.

When no steam is available for running pumps or heating the oil, several methods of procedure, depending on conditions, may be adopted for getting up steam.

1st. If steam atomizers are installed, the furnace arrangement is usually such as to permit the building of a wood fire under one of the main boilers and starting the oil pumps and burners when sufficient pressure has been raised. In this case care should be taken that the air spaces for admitting air for combustion do not get clogged up with old nails or other refuse from the wood fuel. This method is not adaptable to mechanical atomizers.

2d. If the installation is of sufficient size, a donkey boiler will be provided which may be fired with coal or wood or by oil burned by some anti-spraying means. This is the safest and best and most practical means of getting up steam—the donkey boiler being used to run the pumps and operate the heaters while raising steam on the main boilers. In fact, some auxiliary means of obtaining steam is almost indispensable where viscous oils are used, which require heating in the tanks before they can be pumped.

3d. A variation of the standard donkey-boiler plan is the installation of a small flash boiler or coil for generating steam. These can be adapted for burning oil by the pan or trough method, and designs of apparatus of this type are on the market.

4th. With oils sufficiently limpid to pump without heating, a hand pump delivering oil direct to one or two burners of one of the boilers may be used. This method is employed in the Navy and Coast Guard Service. Usually, oil which can be pumped can be sprayed sufficiently to get up steam slowly, or it is entirely possible to employ special emergency heaters of the open-pan type to heat the oil on the way to the burners.

5th. Providing the vessel is moored near some source of compressed air, the latter may be used to run the oil pump, or live steam may be carried on board by flexible-hose connections.

GAS ANALYSES.

In ordinary operation with oil fuel the absence of all smoke is to be viewed with suspicion on account of the likelihood that this condition represents an excess of air in the furnace and consequent loss in economy. Smoke may result from other causes than lack of sufficient air, as, for instance, imperfect atomization, but it is advisable, notwithstanding, to check the admission of air to give a slight "haze" of smoke from the funnel, as, all things considered, this provides the best rough-and-ready indication of the proper running conditions.

Analysis of the products of combustion is, however, the only sure method of obtaining information by which to adjust furnace conditions to give the maximum efficiency. There are several types of apparatus on the market which indicate the percentage of carbonic acid gas and thus provide very satisfactory evidence of the results being obtained in the furnace. One of these is known as the Hays apparatus, this being a convenient modification of the well known Orsat apparatus.

To some extent the operator can judge of the fire by inspection through suitable "peep holes," but personally I am disposed to distrust this evidence and to depend upon the analysis of the waste gases whenever pos-

sible. Taken by itself, the gas analysis indicates, better than any other one thing about a boiler plant, what sort of economic results are being obtained.

OIL AND COAL IN COMBINATION.

The report of the U. S. Naval Liquid Fuel Board in 1904 contained an emphatic recommendation against the use of oil and coal combined, ending as follows:

"The good of the service requires that any installation attempted should depend alone upon oil as a fuel and not on any combination with coal."

The fact that the first use of the mechanical atomizer by the U. S. Navy was for oil in combination with coal, and that today there are eight powerful battleships so equipped, does not indicate that the Board's recommendation was disregarded. On the contrary, U. S. naval policy is committed to the rapid introduction of oil only, as a standard in all ships, and experience has demonstrated the soundness of this policy. But where coal is the main fuel, oil can be used effectively as a "booster" for obtaining *more steam*, or for use in port without coal, though it is recognized that the two fuels cannot both be burned in the same furnace at the same time with the best economy from either, notwithstanding some considerable experimenting with ingenious devices for burning the oil above the coal bed.

TESTS OF BOILERS USING OIL FUEL.

It is well recognized that results expressed in pounds of oil per indicated horsepower-hour contain too many variables and too often include data which are unreliable to make them of value as tests of either boilers or burners. This is exemplified in the report given later by Mr. L. D. Lovekin, of the trial trip results of the U. S. S. *Melville*, in which the oil per shaft horsepower, including the fuel used for operating a large number of auxiliaries, would scarcely foreshadow the excellent work done by the boilers and burners, where, owing to Mr. Lovekin's supervision of the combustion, a boiler and furnace efficiency of nearly 82 per cent. was obtained.

To learn decisively what the boilers and burners are doing it is necessary to make accurate observations of the water evaporated and oil burned and the conditions under which this is carried out. Here, again, errors are likely to be introduced which vitiate the results, and unless special precautions are taken by skilled engineers, the figures may be very misleading. *Ex parte* tests, particularly those wherein all the conditions are not reported or where the data furnished are insufficient to permit checking up the figures by means of a heat balance, or otherwise, do not warrant recognition before scientific bodies.

I am fortunate in being able to present the results of evaporative tests of three different types of water-tube boilers (Normand, Yarrow and Babcock & Wilcox) which were tried out under the able direction of Lieutenant Commander John J. Hyland, U. S. N., with a trained corps of assistants at the U. S. Fuel-Oil Testing Plant at the Philadelphia Navy Yard in 1912 and 1913. The results of these tests are shown graphically in Figures 42, 43 and 44, which are reproduced from the charts in Commander Hyland's report.

In the tests of the Normand and Yarrow boilers, the Bureau Burner Type "Y" was used. In the tests of the Babcock & Wilcox boiler, Bureau Burners and Peabody Burners were used alternately.

Through the courtesy of Mr. Angelo Conti, of the Bureau of Steam Engineering, who coöperated with Commander Hyland in conducting some of the tests of the Babcock & Wilcox boiler, I have received the following concise report. The figures on that heat balance will be of special interest. These were prepared especially for this paper and have not been published elsewhere.

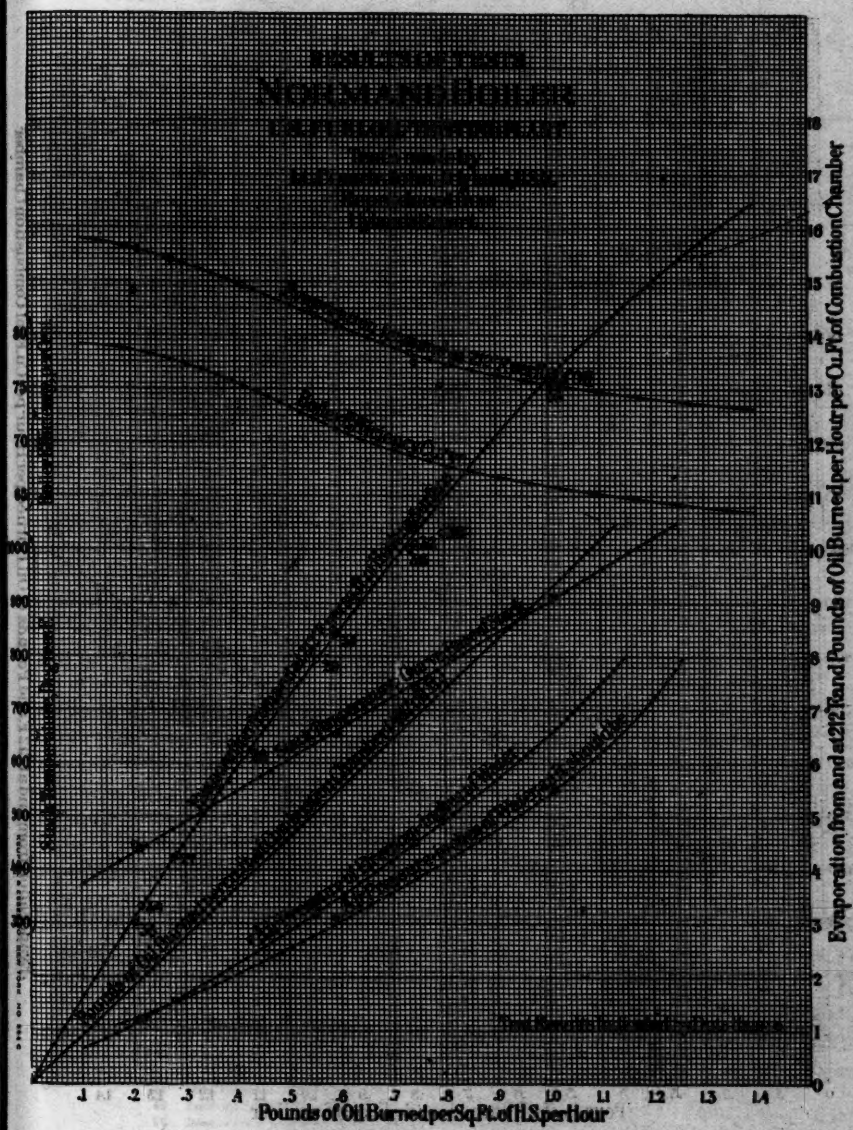

Pounds of Oil Burned per Sq. Ft. of H.S. per Hour
Evaporation from and at 212° F. and Pounds of Oil Burned per Hour per Cu. Ft. of Combustion Chamber

FIG. 42.—TESTS OF NORMAND BOILER.

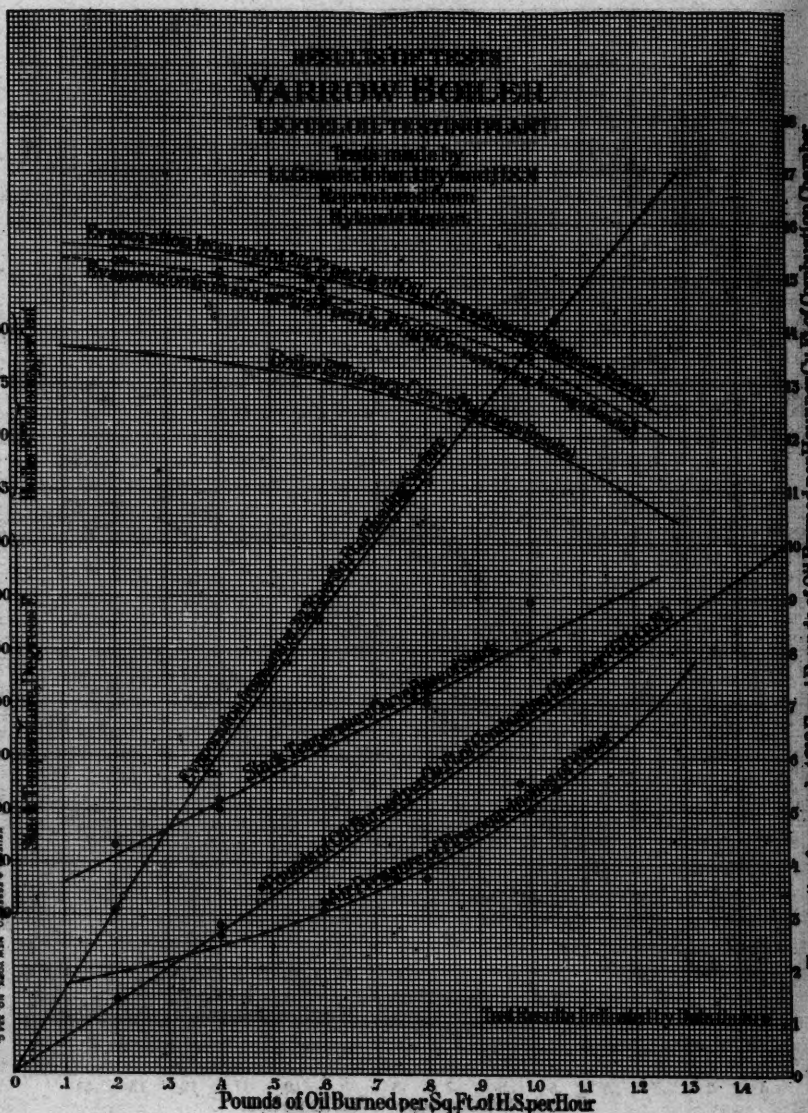
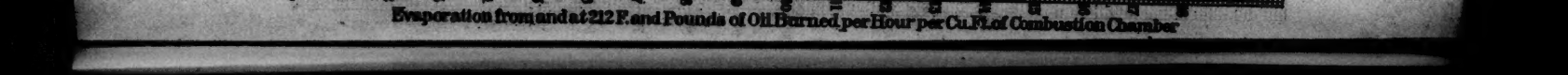


FIG. 43.—TESTS OF YARROW BOILER.


Evaporation from and at 212 F. and Pounds of Oil Burned per Hour per Cu. Ft. of Combustion Chamber

TESTS OF HEAT

FUEL OIL TES

1	Test No.	9
2	Date, 1913	July
3	Barometer	3
4	Length of test averaged, hours	
5	No. of burners used	
6	Aggregate opening of air registers, sq. ins.	7
	Steam Observations—	
7	Steam pressure, lbs. gauge	30
8	Calorimeter, lower therm. °Fahr.	31
9	Calorimeter, normal reading °Fahr.	31
10	Feed temperature at boiler °Fahr.	19
11	Water actually evaporated, lbs. per hour	13,01
	Oil Observations—	
12	Oil burned, lbs. per hour	97
13	Oil pressure at burners, lbs. gauge	19
14	Oil temper. at burners, °Fahr.	18
	Air Observations—	
15	Dry bulb °Fahr.	7
16	Wet bulb °Fahr.	6
17	Fireroom temper. °Fahr.	9
18	Stack temper. °Fahr.	44
19	Fireroom pressure, ins. of water	
20	Velocity head, by Pitot Tube, ins. of water	
21	Smoke, Ringelmann scale	0—
	Flue Gas Analysis, from First Pass—	
22	Carbon dioxide, per cent	1
23	Oxygen, per cent	
24	Carbon monoxide, per cent	
25	Nitrogen (by difference) per cent	8
	Calculated Results—	
26	Steam quality	
27	Factor of evaporation	
28	Actual evaporation per pound of oil, lbs.	1
29	Equivalent evaporation per pound of oil, lbs.	1
30	Actual evaporation per sq. ft. of H. S.	
31	Equiv. evaporation per sq. ft. of H. S.	
	Oil Results—	
32	Oil burned per sq. ft. of H. S., lbs. per hour	
33	Oil burned per cu. ft. of furnace, lbs. per hour	
34	Oil burned per burner, lbs. per hour	2
	Air Results—	
35	Relative humidity, per cent	4
36	Dew Point °Fahr.	5
37	Moisture, lbs. per cu. ft.	
38	Weight of air at atmospheric conditions, lbs. cu. ft.	
39	Forced draft blower output, cu. ft. p. m.	6,2
40	Air supplied to burners, cu. ft. p. m.	3,3
41	Velocity thro. vanes of air registers, ft. p. m.	6,3
42	Cu. ft. of air per pound of oil	2
43	Cu. ft. of air theoretically required for complete combustion of one lb. of fuel	1
44	Excess air, per cent	
	Results from Dry Gases and Ultimate Analysis—	
45	Lbs. of dry gases per pound of fuel	
46	Lbs. of dry air per pound of fuel	
47	% excess air over amount theoretically required for complete combustion	

Test No.		93	
		B.T.U.	Per cent
48	Heat utilized	15,536	79.67
49	Loss by imperfect combustion		
50	Loss with dry chimney gases	1,473	7.54
51-a	Loss with moisture from hydrogen in the fuel	1,366	
b	Loss with moisture in the fuel	6	7.13
c	Loss with moisture in the air	20	
52	Radiation and error	1,125	5.76
53	Total	19,525	100.00

...STS OF EXPERIMENTAL OIL-BURNING BABCOCK & WILCOX BOILERS.

AT

...FUEL OIL TESTING PLANT, U. S. NAVY YARD, PHILADELPHIA, PA.

	93.	94	95	96	97	98	99
.....	July 16	July 16	July 17	July 17	July 23	July 24	July 25
.....	30.12	30.035	30.01	29.96	30.085	29.855	30.035
.....	2	3	3	3	3	4	3
.....	3	5	6	10	8	10	13
.....	77.1	128.5	205.6	270	206.8	270	334
.....	300	300	300	300	300	300	302
.....	310	309	296.2	297.3	303.1	292.3	272.7
.....	312	312	312	312	309	309	309
.....	199	200.6	201.3	200.6	200.2	200.7	200.6
.....	13,052	23,644	37,504	48,216	36,638	47,662	60,325
.....	871	1,576	2,532	3,192	2,486	3,182	4,005
.....	191	218	196	207	188	194	193
.....	180	180	180	180	180	180	181
.....	78.9	84.1	78.8	79.8	87.2	86.0	80.35
.....	65.3	67.5	67.6	68.4	72	73	64.5
.....	97	99.7	94.3	96.6	101	98.4	96.9
.....	446	509	620	685	649	690	720
.....	1.00	2.00	3.26	4.35	3.21	4.20	5.11
.....	.39	.73	1.86	2.48	1.67	2.54	3.516
.....	0—2	0—1	0—1	0—1	0—1	0—1	0—1
.....	12.625	14.266	14.2	14.66	14.34	15.106	15 15
.....	5.04	2.71	2.75	2.15	4.34	3.093	2.73
.....	.00	.00	.00	.00	.00	.00	.00
.....	82.335	83.024	83.05	83.19	81.32	81.801	82.12
.....	.999	.9982	.985	.974	.9966	.9903	.9789
.....	1.0684	1.0662	1.0545	1.046	1.0652	1.0594	1.0501
.....	14.984	14.983	14.812	15.104	14.738	14.98	15.062
.....	16.01	15.98	15.62	15.80	15.70	15.87	15.82
.....	3.263	5.911	9.376	12.054	9.159	11.915	15.081
.....	3.49	6.30	9.89	12.61	9.76	12.62	15.84
.....	.218	.3945	.633	.798	.6215	.795	1.001
ur.....	1.95	3.54	5.69	7.18	5.58	7.16	9.00
.....	290	315.6	316.5	319.2	311	318.2	306
.....	47.5	42.0	55.5	55.3	47.7	53.2	42
.....	57.2	58.5	61.5	62.5	64.6	67.0	54.7
.....	.0007495	.000788	.0008705	.00090	.0009646	.000855	.0006038
. ft.	.07375	.0729	.07385	.07375	.07265	.0725	.074
.....	6,280	9,910	14,700	18,000	14.860	18,340	21,380
.....	3,360	5,710	9,125	11,450	9,335	11,840	13,980
.....	6,260	6,400	6,400	6,110	6,540	6,320	6,030
.....	231.2	217	216	215	225.2	223.2	209.6
plete com-							
.....	193.3	196.5	194	194.2	197.2	197.5	193.5
.....	19.7	10.5	11.3	10.7	14.25	13.0	6.3
sis—							
.....	17.156	15.263	14.645	14.878	15.23	14.49	14.44
.....	16.98	15.15	15.23	14.78	14.77	14.10	14.11
d for com-							
.....	30.66	14.3	14.53	10 95	25.72	13.92	14.62

HEAT BALANCE.

93		94		95		96		97		98		99	
T.U.	Per cent	B.T.U.	Per cent	B.T.U.	Per cent	B.T.U.	Per cent	B.T.U.	Per cent	B.T.U.	Per cent	B.T.U.	Per cent
5,536	79.57	15,507	79.42	15,187	77.84	15,331	78.52	15,235	78.04	15,400	78.88	15,351	78.64
,473	7.54	1,535	7.15	1,857	9.51	2,153	11.02	2,052	10.51	2,111	10.81	2,210	11.32
,366		1,396		1,463		1,495		1,471		1,496		1,514	
6	7.13	6	7.38	6	7.64	6	7.50	6	7.69	6	7.77	6	7.87
20		20		23		23		25		14		17	
,125	5.76	1,061	6.15	1,019	5.21	516	2.66	736	3.76	498	2.54	427	2.17
,525	100.00	19,525	100.00	19,525	100.00	19,525	100.00	19,525	100.00	19,525	100.00	19,525	100.00

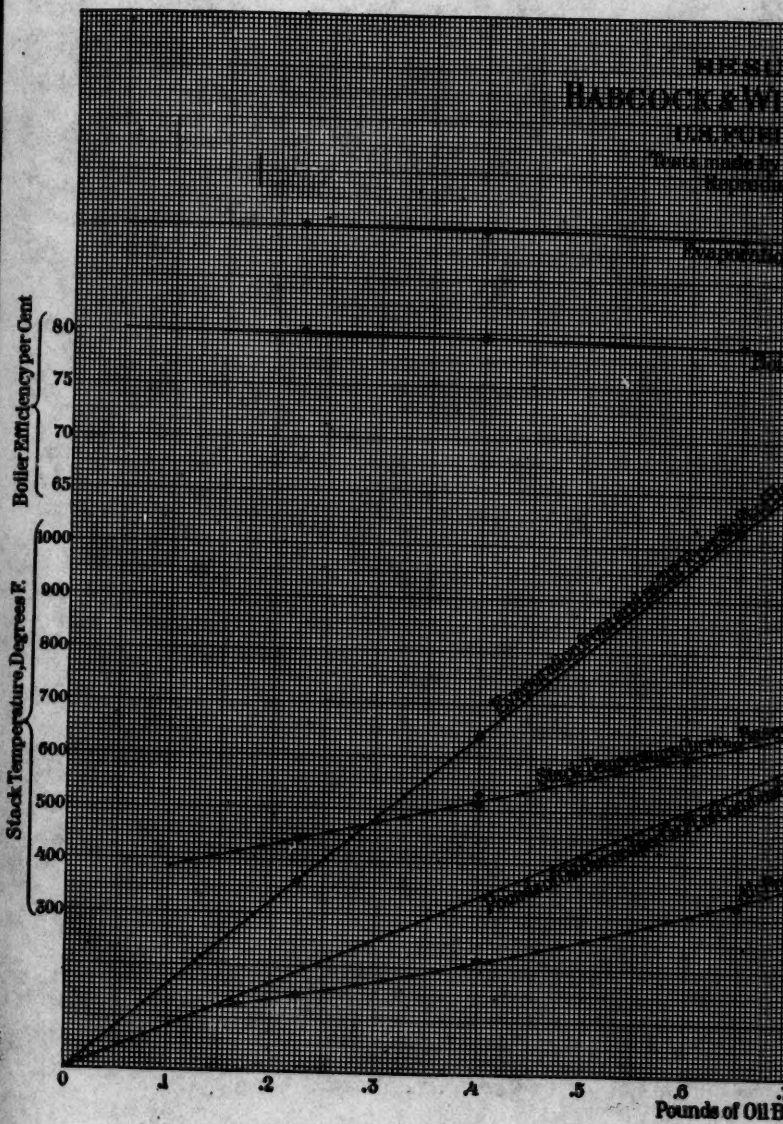
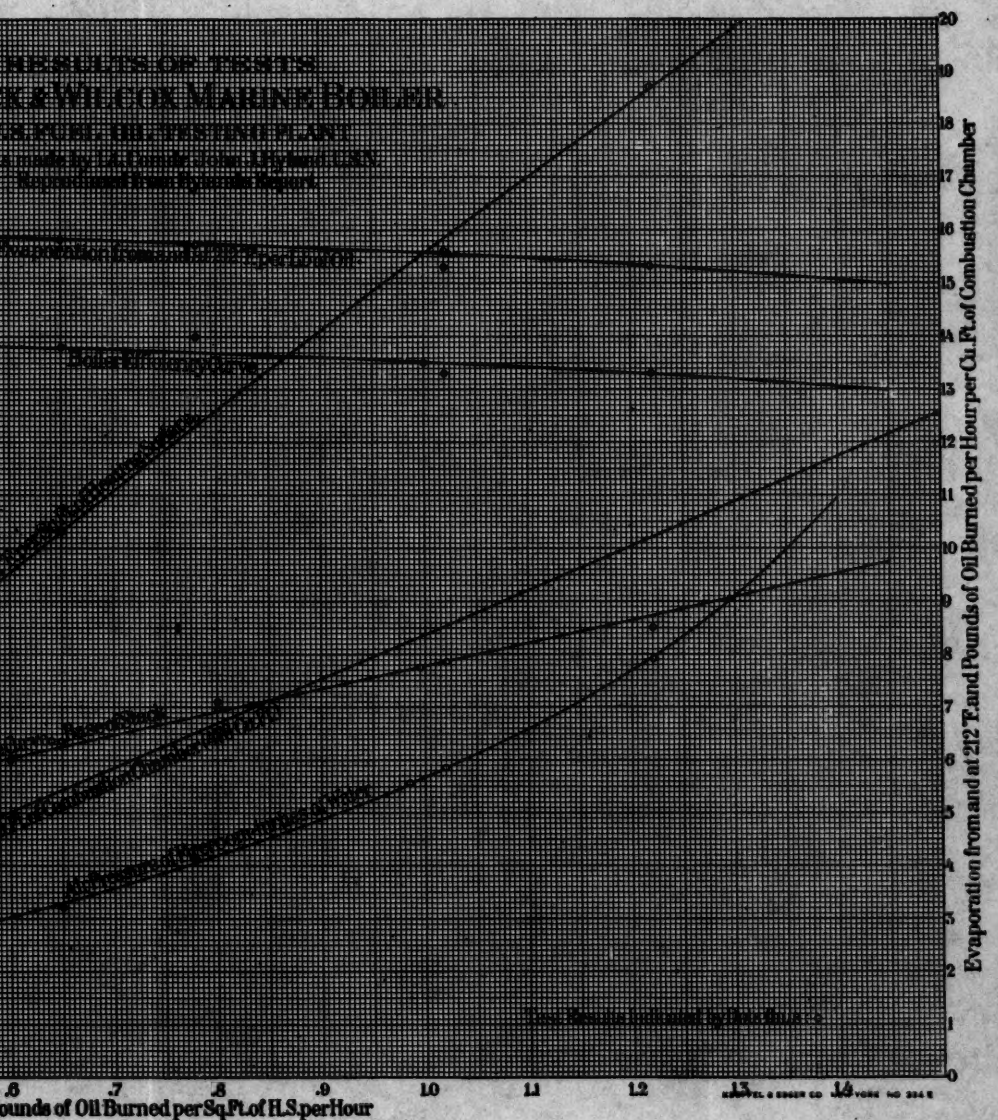


FIG. 44.—TESTS OF



Tests of Babcock & Wilcox Boiler.

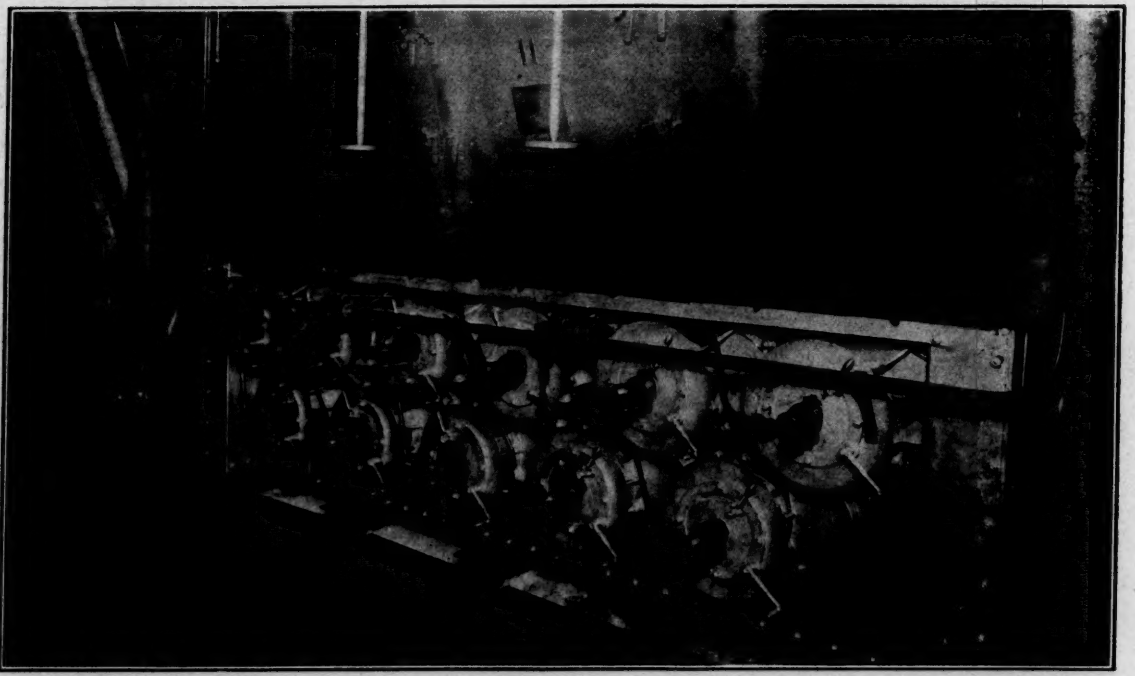


FIG. 45.—BABCOCK & WILCOX BOILER ON U. S. S. "PENNSYLVANIA" FITTED WITH PEABODY BURNERS.

Previous to Mr. Conti's attendance at the tests Commander Hyland ran a series of tests on the Babcock & Wilcox boiler, one of which was made at the highest possible capacity obtainable at the plant—this was limited by the air pressure, 7 inches in the closed fireroom, which was all the fan was capable of producing. During a period of three hours an average evaporation of 18.7 pounds of water into dry steam from and at 212 degrees F. was obtained per square foot of heating surface per hour, which is believed to be the highest marine-boiler capacity of authentic record. At the same time an evaporation of 15.3 pounds of water per pound of oil from and at 212 degrees F. was secured—the oil burned per square foot of heating surface per hour being 1.23 pounds.

Babcock & Wilcox boilers of similar design to that tested at League Island are being installed in the U. S. Super-Dreadnaughts *Oklahoma, Pennsylvania, Mississippi, Idaho* and *Arizona;* each of these vessels will use oil exclusively. Figure 45 shows one of the boilers of the *Pennsylvania* fitted with Peabody mechanical atomizers.

Report of Tests on Experimental Oil-Burning Babcock & Wilcox Boiler at the Fuel-Oil Testing Plant.

By Angelo Conti.

"Following the adoption of the Babcock & Wilcox type of boiler for the battleship *Oklahoma,* burning fuel oil exclusively, a boiler of the *Oklahoma* type was purchased for experimental purposes and thoroughly tried out at the Fuel-Oil Experimental Plant, U. S. Navy Yard, Philadelphia.

"Particulars of this boiler are as follows:

No. of sections	22
No. of groups of 4—3-in. diam. tubes in each header	9
Total number of 2-in. tubes	792
Length of tubes between headers, feet and inches	9–0
Inside diameter of steam drum, feet and inches	3–0
Total heating surface, sq. ft.	4,000
Furnace volume, cu. ft.	445

"The tests reported herein were run under the supervision of Lieutenant Commander J. J. Hyland, Head of the Fuel-Oil Testing Plant, in collaboration with the writer, who was specially detailed by the Bureau of Steam Engineering to assist in the compilation of the technical data taken by the force on duty at the Plant.

"An article by Lieutenant Commander John J. Hyland, U. S. Navy, published in the May, 1914, number of the 'Journal of the American Society of Naval Engineers,' profusely illustrates the type of burners and registers used in these tests and also gives a diagrammatic plan of the Testing Plant. Observations were taken throughout each test at 5-minute intervals, with the exception of chimney-gas analyses, which were taken every fifteen minutes by means of an Orsat apparatus. The evaporation was computed at the end of each hour and the tests continued until it was proved that the results obtained were consistent and accurate.

"In order to allow the boiler to be thoroughly heated up, the first two or three hours of each test were purposely discarded, the enclosed summary representing an average of the observations taken during the last hours of each test. Owing to the uniformity of conditions obtained, as well as the care used in eliminating observational errors, and, finally, the consistency of the results themselves, no doubt can be felt as to the accuracy of these tests, of which the following inserted table gives a summary:

APPENDIX TO REPORT BY ANGELO CONTI.

Method of Obtaining Items in Table.

Item.

1, 2. For reference.

3. Observed.

4, 5, 6. For reference.

7. Observed by spring gage connected to steam drum, pressure, practically constant.

8. From a Barrus throttling calorimeter, fitted with a closed-end standard perforated nipple, connected to the main steam pipe, rising vertically from the steam drum, 18 inches above stop valve.

9. From calibration after each test, taking readings with the pressure both rising and falling with no steam leaving the boiler except through the calorimeter.

10. Observed from calibrated thermometer located on the branch leading from main feed pipe to boiler.

11. Total weight of water fed to boiler corrected hourly for inequality of water level, as found from calibration of steam drum.

12, 13, 14. Observed.

15, 16. From dry and wet-bulb thermometers mounted on a perforated board placed on the suction duct of the forced-draft blower to insure a good ventilation,

17. Observed.

18. Observed from a Hohmann and Maurer, nitrogen-filled mercurial pyrometer calibrated at the Naval Engineering Experiment Station, U. S. Naval Academy, Annapolis, Md.

19. Observed by U-gage.

20. From a standard Pitot tube placed in the center of the forced-draft blower-discharge pipe about 5 feet from the top. This pipe is 24 inches inside diameter, 15 feet high, and the top is belled out and open to the fireroom. The Pitot tube is connected to an Ellison inclined gage graduated to hundredths of an inch.

21. From observation through a large mirror adjacent to a Ringelmann chart.

22, 23, 24, 25. Orsat apparatus, drawing samples through a long perforated tube from the first pass. This location was selected on account of a leaky casing, as evidenced by the lower percentage of CO_2 shown by a Uehling continuous-recording apparatus drawing from the base of the stack.

26. Computed from the formula $X = \frac{.47\ (T - t)}{L} \times 100$, in which X = percentage of moisture; T = calibration reading of lower thermometer (item 9); t = test reading of lower thermometer (item 8); L = latent heat of steam at boiler pressure.

27. Factor of evaporation $= \frac{L + (h - h_o)}{970.4}$, where L is the latent heat of vaporization, h the heat of the liquid, h_o is the number of heat units contained in the feed water entering the boiler and 970.4 represents B.t.u.'s required to convert one pound of water already heated at 212 degrees F. into steam at atmospheric pressure.

28. Item 11 ÷ item 12.

29. Item 23 × item 27.

30. Item 11 ÷ 4,000 sq. ft. H. S.

31. Item 31 × item 27.

32. Item 12 ÷ 4,000.

33. Item 12 ÷ 445.

34. Item 12 ÷ item 5.

35, 36. From items 15 and 16 entered in the Psychrometric Tables published by the Weather Bureau.

37. Density of aqueous vapor from Marks & Davis Steam Tables, corresponding to item 36, multiplied by item 35.

38. The weight of one cubic foot of dry air is computed from the formula:

$$P = \frac{.080723}{1 + .0020389\,(t - 32)} \times \frac{b - .378\,e}{29.921}$$

where t is item 15, b is the barometer pressure corrected to the static pressure of the air in the discharge pipe of the forced-draft blower, expressed in inches of mercury; and e is the pressure due to the vapor in the air also in inches of mercury. Item 37 is added to P.

39. The velocity of the air at the center of the blower-discharge pipe is computed from the formula

$$V = 1{,}097 \sqrt{\frac{\text{item } 20}{\text{item } 38}} \text{ feet per minute.}$$

The average air velocity is from 8 per cent. to 10 per cent. lower than the center velocity, the reduction factor being taken from the results of tests made at the University of Wisconsin and borne out by tests made at the Naval Engineering Experiment Station (see JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, November, 1912, page 1143). As stated above, the discharge pipe has an internal diameter of 24 inches.

40. Item 39 corrected from results of leakage tests. (See note.)

41. $\dfrac{\text{Item } 40 \times 144}{\text{Item } 6}$.

42. Item 40 ÷ item 12.

43. Item $43 = \dfrac{11.5C + 34.8\left(H - \dfrac{O}{8}\right) + 4.35S}{\text{Item } 38}$ cu. feet per pound of fuel,

where C, H, O and S are the percentages by weight of carbon, hydrogen, oxygen and sulphur, respectively, as found from the ultimate analysis of the fuel.

44. (Item 42 ÷ item 43) × 100.

45. Computed from formula

$$W = \frac{4\,CO_2 + O + 700}{3\,(CO_2 + CO)} \times C$$

where CO_2, O and CO are items 22, 23 and 24, respectively, and C represents the amount of carbon, by weight, per pound of fuel as found from the ultimate analysis.

46. Computed from formula $\dfrac{3.03\,N}{CO_2 + CO} \times C$, where N, CO_2 and CO are items 25, 22 and 24, respectively, and C represents the amount of carbon per pound of fuel, as found from the ultimate analysis.

47. Computed from formula $\dfrac{O}{.261N - O} \times 100$, where O and N are items 23 and 25.

Heat Balance.

48. Item 29 × 970.4.

49. Loss in B.t.u. per pound of fuel $= 10{,}120\,\dfrac{CO}{CO_2 + CO} \times C$, in which CO and CO_2 are percentages by volume from the flue-gas analysis, and C is the proportion of carbon in the fuel as determined by ultimate analysis.

50. Item 45 × (Item 18 — Item 17) × .246 × C.
The mean specific heat of dry chimney gases is approximately taken as .246 and C is the proportion of carbon in a pound of fuel, as determined by the ultimate analysis.

51-a. Loss in B.t.u.'s per pound of fuel = $9H(H_T - h_t)$ where H = weight of hydrogen contained in one pound of fuel from ultimate analysis.
H_T = total heat per pound of steam at stack temperature.
h_t = heat per pound of water at fireroom temperature.

51-b. Loss in B.t.u.'s per pound of fuel = $W(H_T - h_o)$ where W = weight of water contained in one pound of fuel.
H_T = total heat per pound of steam at stack temperature.
h_o = heat per pound of water at the temperature of the oil (Item 14).

51-c. Loss in B.t.u.'s per pound of fuel = $\frac{\text{Item 46}}{\text{Item 38}}$ Item 37 $(H_T - h_t)$ where
H_T = Total heat per pound of steam at stack temperature.
h_t = Heat per pound of water at fireroom temperature.

52. By difference.

53. From ultimate analysis of fuel, as follows:

Kind of oil	Texas	Hydrogen	12.70
Gravity, ° Baumé	26	Nitrogen	.19
Flash Point, ° Fahr.	222	Sulphur	.30
B.t.u.'s per pound	19,525	Water and sediment	Traces
Carbon	86.00		

Note.—In order to determine the net amount of air supplied to the burners, the output of the forced-draft blower was corrected by the air leakage through the boiler casing, and a special test was run for this purpose.

Both the experimental Normand and Yarrow boilers were made air-tight by means of plate covers bolted on top of their stacks, while the openings of the air registers in the furnace front of the B. & W. boiler were closed tight with canvas, held on with battens. The stack cover of the B. & W. boiler was removed and the damper opened. The fireroom was closed tight and, as no steam was available, the forced-draft blower was run with compressed air, its speed being regulated so as to vary the fireroom pressure from one inch of water up to nearly six inches, which was the maximum that could be obtained with pressure of compressed air at 85 to 90 pounds.

The blower output was measured as on evaporative tests by means of a Pitot tube, and obviously represents the leakage through the fireroom and the boiler casing.

It must be noted that on the leakage test the boiler was cold, which probably accounts for some of the discrepancy between the amount of air thus measured and the amount found from the chimney gas analysis. Considering, however, the number of factors involved in the computation of items 44 and 47, there exists a fair agreement between these two widely differing methods.

*Official Four-Hour Ten-Knot Run of the U. S. Torpedo Destroyer Tender "Melville," July 18, 1915.**

Average r.p.m.	Speed.	S.H.P.	Pounds of oil per hour.	Lbs. of water per hour.	Water evaporated per lb. of oil.	Oil per sq. ft. of H.S.
70.25	10.15	1275	2564	37,200	14.52	.7

The oil weighed 7.24 pounds per gallon. The temperature of the feed water varied from 140 degrees to 160 degrees. The B.t.u.'s. in the oil were about 19,000; so that, by taking the evaporation—which was 14.52—

*From a letter by Mr. Luther D. Lovekin, Chief Engineer of the New York Shipbuilding Co., to the builders of the boilers, The Babcock & Wilcox Co., in which occurs the statement "During a four-hour continuous speed trial of the U. S. Destroyer Tender *Melville* we obtained results in oil burning that so far as my knowledge is concerned have never been equalled."

and multiplying the same by the factor 1.103 (which allows for a reasonable degree of moisture) we obtained about 16 pounds of water from and at 212 degrees for the average during the entire four hours; the readings were taken every thirty (30) minutes. The CO_2 was 13 per cent. The CO was zero; the oxygen—about 3 per cent. during the entire run.

The air pressure in the fireroom was never more than 3 inches and occasionally dropped as low as 2½ inches. The fuel-oil temperature was 160 degrees; the flue gases were from 500 degrees to 525 degrees by electric pyrometer. The water in the gage glass was from 3½ inches to 4 inches at all times and the smoke was of light brown.

From the above results it will be seen that we obtained a boiler efficiency of about 81.7 per cent., which is, in my opinion, most remarkable. Further than this, there were several periods when we were evaporating 15.18 pounds of water per pound of oil from a feed temperature of 160 degrees into steam of 250 pounds per square inch; and, had the trial continued for a longer period, I am positive that we could have averaged 15 pounds of water per pound of oil for another four hours.

The above trials were made with one of the two Babcock & Wilcox boilers furnished for this vessel, and which were fitted with the Schutte & Koerting oil-burning outfit complete. There were ten (10) burners in each boiler, and each burner was surrounded by an adjustable air register of the regular Koerting type; a full view of which can be had from the accompanying drawings. (See Fig. 34A.)

Prior to running these tests we had just completed a trial of 48 hours' continuous speed at 15 knots, with both boilers in operation. The earlier part of the trial, or for about 12 hours' run, appeared very unsatisfactory, as our average water evaporated per pound of oil fell in the neighborhood of 13 pounds. I had based my calculations on an average of 14 pounds of water from feed temperature of 200 degrees into steam at 250 pounds pressure, and the results were falling far short of my expectations. After making several comparative sheets hourly, in which the basis of comparison was the boiler tested at the League Island Navy Yard, I felt convinced that the principal difficulty that we were encountering was that of unclean surfaces. We therefore proceeded to clean the surfaces, as well as could be under operation, and we immediately began to see a great improvement in the evaporation, the next 36 hours showing an evaporation of from 13½ to 14 pounds of water per pound of oil. This convinced me of the fact that the boilers were not clean, and upon the completion of the 48-hour run, the sides of the boiler were opened up and the boiler tubes thoroughly cleaned, after which we started on our four-hour run at ten knots speed and obtained the results hereinbefore referred to.

It might be well to mention the fact that we had installed on this vessel a Hays Continuous CO_2 Recorder, which enabled us to keep track of the CO_2 at all times. We also took several snatch samples of gas for analysis in order to check the continuous recorder and at all times we found the readings to be consistent. Furthermore, I might state that, without the use of some such apparatus as this, it would have been impossible for us to have burned the oil in such a satisfactory and economical manner.

The above trials prove, in a great measure, the value of the oil-burning experiment station which was erected by our United States Navy Department at the Philadelphia Navy Yard; for here, as is well known, have been set up and fully tested out three distinct types of boilers:—One being the Yarrow type; one the Normand type, and the other, a Babcock & Wilcox boiler, almost identical to one of the units installed on the *Melville*. Each of these boilers was fully tested out under varying conditions and curves plotted showing their characteristics at various rates of oil burning and with various grades of oil; and, had it not been

for the test on this particular boiler, it would have been a most difficult as well as a most costly experiment to the shipbuilding company to determine at just what point the maximum boiler efficiency was. But, being provided with these data by the United States Navy Department, and knowing that these tests were conducted by disinterested parties, gave us every confidence in the results and we, therefore, looked forward to being able to reproduce them within certain practicable limits. Had it not been for these tests, one might have expected two boilers in operation on the ten-knot run of the *Melville* to give more satisfactory results than one boiler did; but, knowing from the start what the maximum efficiency of this boiler was when 0.8 pound of oil per square foot of heating surface was being used, we, naturally, aimed to keep very close to this point.

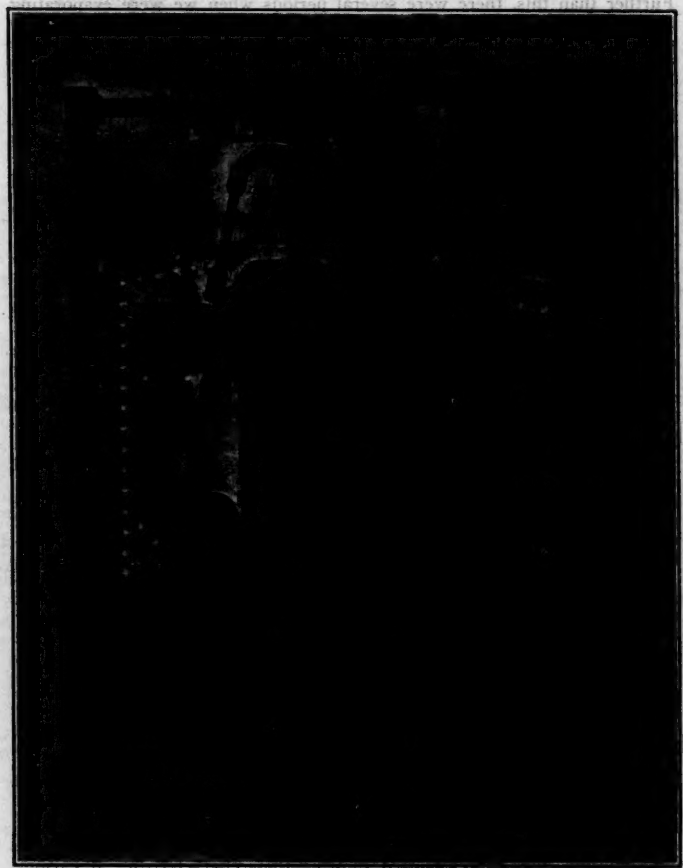


FIG. 46.—COCHRANE PRECISION METER.

I think it is only fair to give the United States Navy Department great credit for the way in which they have taken up the question of oil burning, and to assure them that the great expenditure necessary to carry out these experiments has been fully justified.

Another feature of the *Melville's* trial that is worthy of the greatest consideration, and to which I take great pleasure in calling your attention, is the Cochrane Precision Meter with storage chamber, this vessel being the first to which this appliance was ever fitted.

This apparatus, as installed on the *Melville*, is shown in Fig. 46.

The volumetric method is employed, consisting of filling a chamber of known capacity to a fixed level measured in the neck of small cross section where considerable variation in level would cause only a slight error. A light, easily moved pilot valve is actuated by floats at the measuring level of each of the two measuring tanks. This pilot valve admits steam to suitable cylinders which automatically operate the filling and emptying valves which are of the Cochrane rotary self-cleaning type. The apparatus is so designed that the valves cannot rotate until the compartment in question is either completely full or completely empty as the case may be, regardless of the rate at which water is being passed through the apparatus.

The lower storage tank is used for storing the measured water. The meter is fitted with a counter and clock-driven timing mechanism, so that the number of times the compartments have been filled and emptied in a specified time are recorded. These meters are automatic in their operation and require no attention whatsoever from anyone. They worked continuously during our entire trial trip without a hitch of any character. Their accuracy is indisputable,—calibration tests proving them to be accurate within a fraction of 1 per cent. Without a meter of such reliability, one might cast grave doubts as to the results of our tests, but we feel that they are conclusive.

Extracts from Report of Official Trials U. S. Torpedo Boat Destroyer "Wadsworth," June 21, 1915.

		Full Power
Speed, knots	16.004	30.673
Total shaft H.P.	1,436	16,100
Water (all purposes) per S.H.P., lbs. per hour	22.723	12.436
Oil per S.H.P., lbs. per hour	1.546	.958
Oil per burner, lbs. per hour	395	422
Mean air pressure, inches	2.55	6.01
Actual evaporation water per lb. of oil, lbs.	14.694	12.982
Steam pressure at boilers, lbs. per sq. in.	150	250.1
Feed temperature, degrees F.	230.25	186.25
Boilers in use	1	4
Fuel Oil:—		
Specific gravity = 8,726		
B.t.u. per lb. = 19,658.5		

Description of Propelling Machinery.—There are four water-tube boilers of the Normand return-flame type, having a total heating surface of 21,500 square feet. The ratio of heating surface to furnace volume is 10.34. Each boiler has twelve burners of one of the Bureau of S. E. patterns, but only nine in each boiler were in use on the full-power official trial.

There are two independent shafts each driven by one high-pressure and one low-pressure Parsons turbine running at high speed, reduced by mechanical gearing to about 450 revolutions on main shaft at full power.

The gears are single helical arranged so that the greater part of the propeller thrust is balanced by the axial steam thrust of the turbines acting

through the gears. A small thrust bearing is provided on the main shaft, forward of the gearing, to take the unbalanced portion of the thrust.

The vessel was built by the Bath Iron Works and trials run by them under the direction of the U. S. Navy Board.

"Tallapoosa" Tests.

Previous to the installation of oil burners to operate under low natural-draft conditions on the U. S. Coast Guard Cutter *Tallapoosa*, The Babcock & Wilcox Company made some evaporative tests at their Bayonne plant on a Babcock & Wilcox marine boiler fitted up for experimental purposes. The tests were made by Mr. Thomas B. Stillman, Jr., and while they were not intended for publication, every effort was made to secure correct data and the heat balance indicates a satisfactory degree of accuracy.

The oil burners and air control are shown in Figure 47 as later installed on one of the boilers of the *Tallapoosa*. (See also Fig. 33.)

While primarily made to observe results with low natural draft, a jet in the stack and the airtight house in which the boiler was installed, fitted with forced draft on the closed fireroom principle, permitted tests being made also under conditions of forced air pressures approximately equal to 4 inches of water.

The Panuco oil used in the second series of tests was furnished without charge by the Interocean Oil Company, and Dr. Leonard Waldo and Mr. C. K. McFadden of this company were present during many of these runs.

The high oil pressure carried in some of the tests was for convenience only, to avoid changing the size of burner. Attention is called to the gas analyses, which approach those secured by Commander Hyland in his tests of the B. & W. boiler.

A GLANCE BACKWARD.

The last ten years have been marked not only by wide extension in the use of oil fuel for marine purposes, but by the introduction into the market of heavy viscous oils that require heating for use at the burners and for handling by means of pumps through the necessary pipe lines. The matter of viscosity of liquid fuel has become quite as important, therefore, as flash point and heat value, and is being recognized as a salient feature of oil specifications.

The past decade has also witnessed the general introduction of mechanical atomizers for deep-sea service, and the designs of this apparatus have increased in number and excellence.

Experiment along the line of boiler development has, thanks to oil fuel, taken a great step forward, particularly in the matter of high capacity under forced-draft conditions, and results have been obtained which heretofore have only been equalled in locomotive boilers, using coal fuel burned under the very high draft pressures produced by the exhaust from the cylinders passing through a jet in the funnel. Unlike locomotive practice, however, the exceedingly high capacities obtained in marine water-tube boilers with oil fuel have been accompanied by excellent efficiency.

The introduction on the market of heavy viscous oils, the increasing use of the mechanical atomizer for sea service and advance in obtaining high boiler capacity and high corresponding efficiency seem to be the most striking features of recent developments in oil burning.

TREND OF DEVELOPMENT IN IMMEDIATE FUTURE.

It requires no prophetic vision to foresee the continued increase in the use of heavier oils. Barring such liquid fuel as gas-house tar, which, while heavier than water, is very fluid and not in the same class with viscous oils, the heaviest oil I know of being burned is 10 degrees Baumé,

TESTS OF BABCOCK & WILCOX MARINE BOI
WITH PEABODY MECHANICAL

OIL FUEL USED. — FORCED AND NATURAL DRA

Kind of Oil	Navy standard, 24° Baumé, 19,100 to 19,200 B.T.U. p. lb.					
Number and size of burners	4-No. 55	4-No. 55	4-No. 55	4-No. 50	4-No. 45	4-No. 45
Date, 1915	Mar. 6	Mar. 17	Mar. 17	Mar. 17	Apr. 3	Apr. 6
Duration of test, hours	2	2	2	2	2	2
Boiler pressure, lbs.	196	194	193	196	205	206
Temperature of feed water, °Fahr.	40	42	42	42	45	44
Moisture in steam, per cent	.....	.....	.....	.....	.....	.....
Factor of evaporation	1.227	1.225	1.225	1.225	1.223	1,224
Oil pressure at burners, lbs.	137	206	308	297	217	113
Oil temperature at burners, °Fahr.	174	181	190	152	180	133
Draft, boiler side of damper, in.	—0.22	—.31	—.61	—.94	—.87	—.45
Draft, top of 3rd pass, in.	—0.22	—.30	—.59	—.89	—.65	—.32
Draft, in furnace, in.	—0.13	—.15	—.26	—.21	+.57	+.55
Air pressure in closed room, in.	0.00	0.00	0.00	+.31	+3.44	+1.65
Temperature of waste gases, °Fahr.	428	446	509	573	725	565
Analysis of waste gases, Sample taken top of 3rd pass — CO_2, per cent	14.90	14.6	13.6	13.4	12.9	13.3
O, per cent	1.00	1.5	2.7	2.7	2.7	2.9
CO, per cent	0.08	0.0	0.0	0.0	0.2	0.0
N, per cent	84.02	83.9	83.7	83.9	84.2	83.8
Oil burned per hour — Total, lbs.	736.	782	949	1,410	2,324	1,553
Per burner, lbs.	184.	196.	237.	353	581	388
Per cu. ft. F. V., lbs.	3.08	3.27	3.97	5.90	9.75	6.50
Per sq. ft. H. S., lbs.	.268	.284	.344	.512	.830	.564
Water evaporated per hour into dry steam fr. and at 212 °Fahr. — Total, lbs.	11,617	12,374	14,873	22,516	34,616	24,012
Per lb. oil, lbs.	15.80	15.83	15.67	15.98	14.90	15.46
Per sq. ft. H. S., lbs.	4.22	4.50	5.40	8.18	12.57	8.72
Efficiency, boiler and furnace, per cent	80.2	80.0	79.2	80.75	75.28	78.2
Smoke, 5 represents "black"	¾—1	¾	¾	¾	¾	¾

HEAT BALANCES OF BAYONNE EXPERIMENTS, US

Date—1915.	March 6th B.T.U.	%	March 17th B.T.U.	%	March 17th B.T.U.	%
1. Heat absorbed by boiler	15,320	80.20	15,370	80.00	15,210	79.20
2. Heat lost due to burning hydrogen	1,405	7.35	1,432	7.46	1,460	7.60
3. Heat lost in dry flue gases	1,182	6.18	1,323	6.89	1,632	8.49
4. Heat lost due to CO	46	.24	.....	.....	.....	.....
5. Heat lost by radiation and unaccounted for	1,151	6.03	1,081	5.65	904	4.71
Total	19,104	100.00	19,206	100.00	19,206	100.00

USING PANUCO CRUDE PE

Date—1915.	May 6th B.T.U.	%	May 10th B.T.U.	%	May 11th B.T.U.	%
1. Heat absorbed by boiler	14,850	82.05	14,720	81.30	14,425	79.70
2. Heat lost due to burning hydrogen	1,180	6.52	1,170	6.46	1,185	6.54
3. Heat lost in dry flue gases	1,192	6.59	1,147	6.34	1,235	6.82
4. Heat lost due to CO	83	.46	30	.17	35	.20
5. Heat lost by radiation and unaccounted for	795	4.38	1,033	5.73	1,220	6.74
Total	18,100	100.00	18,100	100.00	18,100	100.00

NOTE.—Forced draft supplied both by jet in the stack and by fan discharging into
not determined in tests with navy oil but conditions were similar to subsequent tests when th

MARINE BOILER AT BAYONNE PLANT

ECHANICAL ATOMIZERS.

D NATURAL DRAFT.

THOS. B. STILLMAN, JR.

T.U. p. lb.		Panuco (Interocean Oil Co.), 13° Baumé, 18,100 B.T.U. p. lb.						
4-No. 45 Apr. 6	4-No. 55 Apr. 6	4-No. 55 May 6	4-No. 55 May 10	4-No. 50 May 11	4-No. 55 May 11	4-No. 50 May 12	4-No. 45 May 14	4-No. 45 May 17
2	2	2	3	2½	2½	3	2½	3
206	192	192	189	193	188	196	196	.201
44	44	59	60	61	61	61	61	61
.....	.....	0.0	0.0	0.0	0.0	16/100 of 1%	21/100 of 1%	24/100 of 1%
1,224	1.223	1.207	1.206	1.205	1.205	1.205	1.205	1.206
113	130	249	157	140	167	210	146	242
133	151	261	269	247	270	237	240	269
—.45	—.21	—.20	—.21	—.61	—.33	—.93	—.95	—.93
—.32	—.21	—.20	—.21	—.58	—.32	—.83	—.78	—.60
+.55	—.14	—.12	—.13	—.30	—.19	—.24	+.42	+.38
+1.65	0.00	0.00	0.00	0.00	0.00	+.33	+1.70	+3.52
565	412	451	428	457	438	509	572	615
13.3	14.5	14.4	14.1	14.3	14.2	13.5	13.4	13.8
2.9	1.2	1.8	2.6	2.3	2.6	3.2	3.1	2.9
0.0	0.0	0.14	0.05	0.06	0.07	0.0	0.0	0.01
83.8	84.3	83.66	83.25	83.34	83.13	83.3	83.5	83.29
1,553	630	645	660	992	818	1,380	1,814	2,359
388	158	161	165	248	205	340	454	590
6.50	2.64	2.70	2.76	4.15	3.42	5.7	7.6	9.87
.564	.229	.234	.240	.360	.297	.494	.658	.855
24,012	10,025	9,883	10,010	14,737	12,563	20,106	26,020	33,633
15.48	15.92	15.32	15.16	14.86	15.32	14.79	14.35	14.26
8.72	3.64	3.59	3.64	5.35	4.56	7.30	9.45	12.21
78.2	80.4	82.05	81.30	79.70	82.05	79.35	77.00	76.50
¾	½	½	½—¾	½	½	¼	½—¾	½—¾

RIMENTS, USING NAVY STANDARD FUEL OIL.

March 17th		March 17th		April 3rd		April 6th		April 6th	
B.T.U.	%	B.T.U.	%	B.T.U.	%	B.T.U.	%	B.T.U.	%
15,210	79.20	15,510	80.75	14,460	75.28	15,025	78.20	15,450	80.40
1,460	7.60	1,478	7.70	1,574	8.19	1,482	7.71	1,390	7.23
1,632	8.49	1,842	9.60	2,520	13.07	1,850	9.63	1,148	5.98
.....	.....	.....	.....	132	.69	.....	.....	.....	.....
904	4.71	376	1.95	520	2.77	849	4.46	1,218	6.39
19,206	100.00	19,206	100.00	19,206	100.00	19,206	100.00	19,206	100.00

D CRUDE PETROLEUM.

May 11th		May 11th		May 12th		May 14th		May 17th	
B.T.U.	%	B.T.U.	%	B.T.U.	%	B.T.U.	%	B.T.U.	%
14,425	79.70	14,850	82.05	14,350	79.35	13,925	77.00	13,840	76.50
1,185	6.54	1,174	6.49	1,210	6.69	1,247	6.90	1,276	7.05
1,235	6.82	1,173	6.49	1,507	8.32	1,770	9.78	1,910	10.56
35	.20	41	.23	.....	.....	.....	.....	6	.03
1,220	6.74	862	4.74	1,033	5.64	1,158	6.32	1,068	5.86
18,100	100.00	18,100	100.00	18,100	100.00	18,100	100.00	18,100	100.00

scharging into closed fire-room; all readings are referred to atmosphere. Moisture in steam tests when throttling calorimeter showed steam was dry.

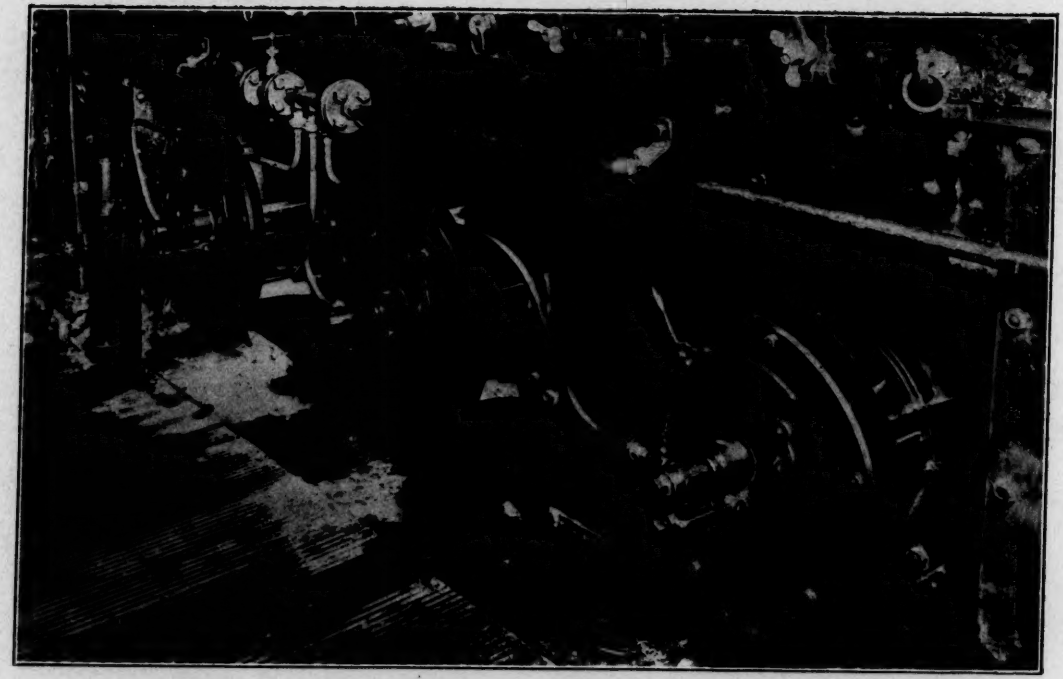


FIG. 47.—PEABODY BURNERS AND AIR CONTROL FITTED TO BABCOCK & WILCOX BOILER, U. S. C. G. CUTTER "TALLAPOOSA."

or the density of water. If it should please the oil producers to put still heavier residuums on the market, these oils can and will be burned successfully. Let us hope that the flash point will be very high.

The "man of mystery," who flourished in the days of Spindle-top, with his superior oil burner with "patent insides," is no longer in evidence, and it is believed that the tendency toward *simplicity* in oil-burning apparatus will continue—which is not to say that we know it all nor that new problems may not be met with, and, judging the future by the past, be successfully solved.

With oil as fuel it is perhaps inevitable that boilers will be forced to still higher capacities to meet new needs—such, for example, as will be met in the steam-driven submersible war vessels. I think, too, that this matter of higher capacities, with other reasons will be a strong influence in the ultimate use of water-tube boilers in the merchant marine to the exclusion of the enormously heavy Scotch boiler. For some years the latter type has been omitted from the battle fleet, the water-tube boiler only being used, and the same considerations that led to its adoption there (less weight, higher capacity, higher economy, greater safety and less cost of maintenance), must eventually bring the water-tube boiler of the better type into its own.

Finally, as already intimated, there is likely to be a move toward larger individual burner capacity and a reduction in the number installed per boiler.

The production of oil is on too great a scale to expect anything but an increase in its use as an ideal fuel for marine purposes.

BIBLIOGRAPHY.

This part of the subject of oil burning has been exceedingly well covered in the list prepared by William B. Phillips and published with his paper on "Fuel Oil in the Southwest" in the Transactions of the American Institute of Mining Engineers in 1914. Mr. Phillips classified and added to the lists prepared by W. H. Dalton, L. V. Dalton, S. L. James and E. S. Ward, for the 1913 Edition of Sir Boverton Redwood's "Treatise on Petroleum."

LETTERS.

I am pleased to be able to present in this paper letters from a few men prominent in the production and the use of fuel oil. Captain A. F. Lucas writes:

"Liquid fuel should only be considered as a factor in the production and generation of power on an extensive scale when an abundant and steady source of supply is assured. Such source should also be located at intervals throughout the various States so as to insure a reasonable cost of transportation to the points of consumption, as is now the case by use of extensive pipe-line systems.

"The United States is therefore particularly fortunate in having within its borders various oil fields through whose pipe lines this vast source of enormous economic importance is being distributed.

"The discovery of oil at Spindle-top, Texas, in 1901 proved the pioneer for the above requirements, for not only did this initial discovery of a very small acreage yield, so far, over 45 million barrels of oil, but holding as it did a preponderant advantage by its location right on the seaboard, led the way for the location of other pools since discovered on the Coastal Plain, which although also confined to a comparatively small area, helped to swell the aggregate production to an enormous figure. This oil was moreover splendidly adapted for fuel purposes. These small but exceedingly productive zones on the Coastal Plains are, however, totally different, geologically speaking, from the older and well known fields of Pennsylvania, West Virginia and Ohio.

"The advent of these unexpected and entirely unlooked for zones in

Texas and later in Louisiana and Mexico added enormously to the wealth of these States, and, encouraged by its almost paramount success, large capital became available for exploration in widely distributed localities, not only in the United States but in every part of the world.

"In this manner the oil regions of the country assumed very important proportions as an available source of the national fuel supply. With its component by-products, this fuel for a time at least threatened to rival even our vast coal deposits.

"The discovery of these large volumes of petroleum in Texas may well be said to mark the point at which this oil production became of National importance. It may be pertinent for me therefore to state how the discovery of the pioneer gusher, now known as the Lucas Gusher, came about.

"In the Fall of 1899 I decided to try out a theory that the slightly raised elevations occasionally met on the Coast Plain of Texas, were in reality surface indications of some geological or economic importance, similar to those I encountered in Louisiana, and which I figured may be overlaid with sulphur, salt or petroleum.

"Against the opinion of leading United States geologists and experts from the Standard Oil Company who examined the locality at my instance, but encouraged by the scant but perceptible odor of SO_2 exuding from the surface, although entirely unaccompanied by any sign of petroleum or asphalt seepage to lend indication of a possible oil field below, I decided to drill a well with the hydraulic method, and selected a location having a slight elevation from the surrounding prairie, the maximum of which did not exceed 12 feet, and of about 275 acres in extent, for my experiment. This low elevation was afterwards known as Spindle-top, a name that has led many to imagine it as a considerable hill, whereas on these level coastal plains it is hardly noticeable.

"The work was delayed by many vicissitudes incidental to pioneer work, but principally on account of having encountered in the process of drilling a heavy quicksand and pressure from below, which pressure filled my line with sand for 100 feet and more, the minute we released the counter pressure with the pump, thus getting the line stuck and impossible to proceed. This was repeated until it brought the proceeding to an acute stage of perplexity, which threatened the dissolution of my little enterprize, as indeed had occurred previously to others in the same effort, a thing that I did not know. I finally contrived a simple experiment (the counterpart of pumping feed water into a boiler, which, of course, is held back by its check valve) which really consisted of a wooden check valve proper, located in the coupling connecting two pipes of the line. This device proved at once an absolute success, which permitted me really to complete the well, and I may frankly state here that my success in the enterprize is due entirely to this little mechanism, which is now well known in well drilling and especially where there is pressure from below as the 'Back-pressure valve.' The well was finally completed, or rather forcibly interrupted, on January the 10th, 1901, at a depth of about 1,135 feet.

"The Gusher started through a six-inch line pipe, blowing skyward some 800 feet of four-inch line pipe used as rod in drilling, and carrying away the heavy overhead chocks, sheaves and cable.

"First vomiting the mud we used in drilling, then showers of rocks and fossils, then gas, and finally a steady flow of petroleum that rose to a height of 200 feet above ground, this flow continued without abatement for ten days before we succeeded in capping the well.

"The oil was of 23 degrees B. and emerged from the well at a temperature of about 120 degrees Fahrenheit, with a sulphur content of from 2 per cent. to 4 per cent. During the ten days of unrestricted flow we confined by means of levees, etc., upon an area of 45 acres, about one million barrels.

"The subsequent boom and development is a matter of history, and the

fanatical lengths to which some of the would-be explorers went are almost incredible. Anything in the way of a mound that might be evidence, by stretches of imagination, to indicate the presence of an underlying 'Dome' was drilled for oil, even Indian mounds, and in one instance, a rather prominent 'ant-hill' proved the target for the eager oil boomer.

"However, my contention that the region may be underlaid with either sulphur, rock salt or petroleum was fully proven, in fact, all three being present, to-wit: The cap rock at 900 feet was concretionary lime and calcite, containing from 10 per cent. to 50 per cent. sulphur. The next stratum of cavernous dolomite with fossils is the oil sand containing the oil, while below at about 1,600 feet begins the salt dome, which is pure rock salt and goes down to unknown depth.

"In my earliest explorations in Louisiana I had been fortunate to locate a number of these salt domes, on what is now known geologically as the salt islands, one of which I bored for the late Joe Jefferson with diamond drill to the depth of 2,100 feet, 1,900 feet of which was pure rock salt, and the drill stopped, still in salt.

"The Coastal Plains of Texas contain a number of domes more prominent in size and elevation than Spindle-top, but although they have since been explored with far larger capital than I had resource to at Spindle-top, they have so far yielded no results. Science has therefore still to reveal to us the solution of additional problems in this connection before we will succeed in mastering all the mysteries of this complex type of geology."

The following is from Mr. H. G. Wylie, Vice-President, Mexican Petroleum Company:

"Referring to yours of the 26th ult. (July, 1915), would state that I agree with you that it is dangerous to use a fuel oil which, to reduce its viscosity sufficiently for mechanical atomization, has to be heated beyond its flash point.

"There is an immense supply of Mexican crude oil sufficiently light in gravity to be 'topped,' thereby removing its low flash point constituents, and still furnish a fuel-oil residue of about 16 degrees B. gravity. The topping process will certainly not increase the price of the resulting fuel oil. I consider that an oil heavier than 16 degrees B. gravity is impractical for marine use, especially where the supply is carried in double bottoms."

Dr. L. Weinstein, of the Anglo-Mexican Petroleum Products Company, Limited, writes as follows:

"As to your first question regarding the relation between flash point and Engler viscosity, I am safe to say that there is no difficulty in making fuel oils from Mexican crude to comply with the American specification that the flash point should not be lower than the temperature at which the viscosity Engler equals 8. The following figures refer to various manufactured heavy fuel oils:

°B. Gravity.	°F. Flash.	at °F. 8 Engler.
15	218	182
14	228	193
13	242	200

"I am not in a position to say whether it will be possible to manufacture from Mexican crude by a simple topping process a fuel which complies with the above specification regarding viscosity and flash point. It looks to me as though it will not be possible to obtain oils of light gravity by topping. However, fuel oils of a gravity heavier than 14 degrees B. may be obtained by a simple topping process with a flash point sufficiently high to comply with the American specification. The above only supports the opinion I expressed to you that for future supplies of oil fuel we

can only rely on heavy oils, as the lighter oils will be used exclusively in internal-combustion engines or for refining purposes.

"Whoever contemplates replacing coal by fuel oil today for commercial or defensive purposes must make arrangements to burn the heaviest fuel oils, as only these oils will be available in future. On our works and fleets we have experimented for years with heavy oil and we now find no difficulty in burning an oil of a gravity of 10 degrees B. either on our boats or in our stationary plants. We prefer using the pressure-atomizing systems.

"In our refinery at Tampico we have 5 B. & W. boilers equipped with B. & W. burners and obtain an absolutely smokeless combustion notwithstanding the fact that our boilers are regularly overcharged. In order to obtain good results it is necessary to provide for a good oil heater and ample surface in the strainers. We found that the best temperature for burning the 10 degree B. oil between 300 and 350 degrees F. and that the pressure should be in the neighborhood of 200 pounds per square inch."

Captain C. A. McAllister, Engineer-in-Chief, United States Coast Guard Service, writes as follows:

"If sufficient money were available to make the necessary changes, oil would be used as fuel on every cutter of the United States Coast Guard. As it is, the change from coal to oil is being made as rapidly as possible. Nine vessels out of forty-one are already fitted for oil. It is the ideal fuel for the work performed by the Coast Guard, as it

1. Raises steam quickly for emergencies,
2. Increases steaming radius,
3. Maintains uniform speed; no dropping off 10 per cent. on account of cleaning fires, as with coal,
4. Makes no smoke when properly handled,
5. Is quickly put on board without dirt or fuss,
6. Cuts down fuel bills,
7. Reduces labor costs in fireroom at least a third,
8. Reduces boiler repairs, and cuts down paint bills."

ACKNOWLEDGMENTS.

In addition to the gentlemen whose names I have mentioned in the preceding pages I want to present my acknowledgments to Dr. W. F. Durand, Mr. A. M. Hunt, and other officials of the Congress for their courtesy and help, and also to the many friends who have given me invaluable assistance in the hurried preparation of this paper. I am particularly indebted to Admiral R. S. Griffin, Engineer-in-Chief, and to Captain C. W. Dyson, of the Bureau of Steam Engineering, both of whom have done much to promote the art of oil burning. Captain Dyson's influence in this field has been, perhaps, second only to his famous work on screw propellers.

DISCUSSION.

MR. W. M. MCFARLAND,* Mem. Am. Soc. M. E. (by letter), called attention to the author's long experience with the subject matter of the paper and to the important investigations in the development of efficient oil burning which he had carried out.

The author of the paper was one of the first, he believed, to call attention to the vital importance of correct air admission, and in conjunction with his assistants, Messrs. Irish and Stillman, there had been developed what the writer considered the best scheme of air admission to date.

Some five years ago, when Messrs. Peabody and Irish had brought out their air impeller, an installation came under the writer's notice where there was serious trouble with another form of oil burner, where the vi-

*Manager, Marine Department, The Babcock & Wilcox Co., New York, N. Y.

bration or pulsation was so bad as to literally shake loose the furnace lining. Having been informed of the excellent results obtained with the air impeller, they secured permission to use it, with complete elimination of pulsations. Quite recently a similar case had arisen, and again it was eliminated by the adoption of the air impeller. The writer expressed the view that correct air admission is the vital point in oil burning, as there are a number of burners on the market which spray the oil satisfactorily.

It was at the urgent request of the writer that Mr. Peabody discussed the subject of viscosity at such length. Experience has shown that this subject is not well understood, and that difficulty often arises because the fact is not appreciated that for best results the viscosity at the burners must be within certain limits.

It seemed also that it would be well to have the various viscometers discussed, so that some relation, if only a rough one, between the different readings could be understood. It is very discouraging, to one who is seeking information, to read that the viscosity must be a certain number of degrees by one viscometer, when all his experience has been with another, if there is no knowledge of the relation. The explanation of the different viscometers would seem to indicate that for ordinary users the Engler has the great advantage that it is self-standardizing, and the results are not changed if there is slight wear in the orifice.

Mr. Peabody has very properly called attention to the element of danger when using oils that require heating above the flashpoint. There was a time when it was claimed by some that there was an increase of efficiency by purposely heating the oil above the flashpoint. There is absolutely nothing in this, as shown by all reliable test records. The possible damage which might result from undiscovered leaks when the oil is heated above the flashpoint is so great that the writer believed no such risk should be taken. Oil fuel has so many advantages, and its use is so attractive from many points, that it would be most unfortunate to risk its receiving a bad name from an improper use.

Mr. J. R. Gordon* states that from the experience of the Union Sulphur Company it has been found indisputable, as stated in Mr. Peabody's paper, that heating fuel oil above the flash point introduces an element of danger on shipboard, and this danger ought not to be considered lightly by ship owners, who are, in the last analysis, the ones who are responsible. Many vessels are today operating in regular service with oil in the pipe line leading to the burners, heated perhaps as high as 100 degrees or more above the flash point, and the practice is continued because the oil companies put on the market, at a lower price, oil which makes this practice necessary, and because operating and superintending engineers are careless or ignorant, or have mistaken ideas about the possible dangers. The writer knows of one prominent manufacturer of oil-burning apparatus who has given the matter so little thought as to make the contention that the oil being under pressure, no gasification is possible. But what if a slight leakage in the piping occurs, and a portion of the oil is liberated? Leaks of this kind are possible, and Mr. Gordon says that he can testify to this fact from his own experience on the S. S. *Herman Frasch*, of the Union Sulphur Co.

This vessel is fitted with three Scotch boilers, and in 1912 these were converted from coal burning to oil burning, Peabody mechanical atomizers being installed, with most satisfactory results. The piping was extra-heavy, welded-iron pipe of the best quality, installed in the most careful and workmanlike manner, and tested under hydraulic pressure before oil was introduced.

After some months of operation, the engineer detected oil fumes in pockets in the lower parts of the fireroom, and further investigation re-

*Traffic Manager, Union Sulphur Co., New York, N. Y.

vealed the fact that a slight leak had started at one of the flanges in the oil-delivery line. This led to the making of tests of the oil, which showed it to have a low flash point; and on account of the viscosity, it required heating above this temperature in service.

Considering the continued use of this oil to be dangerous, the oil companies were appealed to for a supply of what was considered to be a "safe oil," but no assurance could be obtained that this would be furnished, except at a price which was prohibitive. Feeling that the situation called for drastic action, as the company positively refused to operate the vessel under conditions which they knew to be dangerous, the boilers were converted back to the use of coal and the use of oil was stopped.

Since that time the oil companies have apparently taken a different view of the matter, as one is now able to get a "safe" oil at a moderate price, and the Peabody burners have been put back on the *Frasch;* and the Union Sulphur Co. is now buying oil which they do not have to heat within about 30 degrees of the flash point.

Mr. Gordon thinks that their experience shows that if owners will insist on a safe oil the oil producers will supply it. If the owners are satisfied to take what is given them—either through ignorance or carelessness—some very serious disaster may forcibly call attention to a situation for which there is no excuse. Mr. Peabody is to be commended for bringing this matter to the attention of oil users.

LUBRICATING BEARINGS.

In this article it is not proposed to deal with the lubricant itself, but with the bearings in which the lubricant is used and the means or methods of getting the lubricant to the bearings.

The general theory of lubricants is that in their use a film of oil or grease is interposed between a moving member and a stationary one. This, I believe, is just one-third of the real facts. Some rather crude experiments convince me that there are, broadly speaking, three films of oil, one which clings to the moving member with more or less tenacity, a second film which clings more persistently to the stationary member, and a third, or neutral, acting between these two. All of these films partake of motion and their speed is never the same. Sometimes unusual and inexplicable action is found in lubricants, but when conditions are carefully considered an explanation is sure to be found, and the mystery so often attributed to the uneven action of oils can be explained. The following is a case in point:

The bearing of a machine gave trouble. It was about 8 inches long and carried a steel shaft about 5 inches in diameter. The bearing itself was of composition of unknown mixture and the work it had to do was quite severe. In order to keep it going without overheating the bearing had to be scraped and touched up about twice a month. After such treatment on one occasion the bearing ran cool for over a month. No change in lubricant had been made and the gain was attributed to a new hand who had done the scraping having been more particular with the work, but the same man touched up the bearing again and to everybody's disappointment no gain over the usual conditions resulted.

Investigation finally proved that this was the cause of the longer run; the new hand, the first time he scraped the bearing, smeared the surface of the shaft with Prussian blue, as is quite usual. In his haste to get the machine going he did not wash off this Prussian blue, consequently this surface evidently had a tendency to hold the lubricant and this prevented the oil from running out as easily as it had done before and formed a

better clinging surface than did the steel itself. Whether this is the exact reason may be questioned, but several trials proved that when the Prussian blue was left on the shaft the running condition of the bearing was maintained for a longer time than when the Prussian blue was carefully removed.

Originally the lubricant was applied directly to a bearing and gravity and viscosity did the work. Little care was taken to protect the oil opening from dirt and dust, and with the slow-moving machinery of the past the demand for improvement in this matter of cleanliness was slow in coming. Oil cups with covers then made their appearance; and these being tight, a step in advance in lubrication was made. The lubricant, however, in the early forms of application could not be seen and the sight-feed oil cup marked another great advance, as while a drop feed had been used in certain positions in engines and other machines the drops were not under control and were often so placed that the wind blew the drops in all directions. The sight-feed cup made it possible to see that the oil started for the bearing, but it did not insure its arrival, and here is the great advantage of what is known as the forced system of lubrication now being almost universally adopted.

This forced system of lubrication cannot be traced to its origin, as far as I have been able to find out. A gentleman by the name of Girdwood, a Scotch engineer, told me as far back as 1876 of having applied it in a Tange engine, which he designed, and which was, according to his statement, the first overhung cylinder engine ever built. He described the system which he applied as a tank hung from the ceiling at a height which gave a pressure of about four pounds to the main bearings and guides, but the crank brasses were lubricated by a wiper cup.

The next engine that I heard of which was fitted with a system of forced lubrication was built in Essen not far from the date given and was the first time that I ever heard of where all bearings were under pressure. Neither of these systems or engines did I personally see, but later I saw a number of engines fitted with the Essen system (if it may be called so properly), and I fitted a number, supplying them to the United States Navy for blowers with the same system which eventually proved perfectly satisfactory. It may be described as follows:

The crank shaft is drilled out so as to allow the oil to pass through the center up through drilled holes in the crank cheeks to the crank-pin outlets, from the central drilling or oil passage to the main bearings. Outlets are provided, the hole in the crank pin providing means to lubricate the pin, and a surplus of oil is forced down the connecting rod to the cross-head pin and guides. If the engine was double the oil passages were continued on through the crank shaft to other bearings. This, of course, demanded an absolutely closed engine in order to preserve the oil, which was copiously provided by means of a single-acting pump directly connected to the engine.

This system has failed in quite a number of cases, known to me, the failures being generally attributed to the fact that as the oil is forced along through the oil passages, should the first bearing encountered be loose, the oil finds its way out so easily that the pressure is reduced on subsequent bearings, resulting in an insufficient supply of oil. While it is a self-evident fact that the conditions noted would cause trouble, a little care on the part of those running the engines will overcome the objection and good results will be obtained. There is, however, another way of overcoming the difficulty, and that is to grade the sides of the oil ducts in the shafts, beginning by making them as large in diameter as possible and reducing them in area as they are carried on. Not giving attention to this varying of size has often given trouble in forced-lubricating systems.

The real objection to this system is that it is not possible to see or feel if the lubrication is being completed, and the passages are extremely

difficult to clean; in fact, cannot be cleaned without entirely dismantling the moving parts of the engine. Again, this system demands somewhat higher pressures than other systems.

A second system of forced lubrication may be termed a trunk-line system. Here the oil is pumped into a large tube from which branches are led to the various parts requiring lubrication. This system, if it is properly applied, is more satisfactory than the one previously referred to because it has the very great advantage of allowing either a visual or a touch system to be employed, either of which will indicate whether or not the oil has reached its destination. And further, by the use of tees instead of elbows, and crosses in the main line, the oil duct can be cleaned by blowing out by steam or swabbed out by waste and wires.

In any system of forced lubrication the fundamental idea is to force a large quantity of oil to the bearings, reclaim this oil and use it again. Before oil can be reused, under these conditions, it should be strained, cooled and allowed to subside; and the subsiding is of great importance, as no system of straining that I have ever seen will remove the very small particles of dirt as does the subsiding tank, and this subsiding must be given time.

I have referred to sight-feed cups, and they, on a gravity-feed system, are admirable, but when it comes to a forced system of lubrication glass openings, in my experience, soon become opaque and useless. In their place I devised and used methods by which the flow of the oil could be felt, but let me say that I have always preferred a single-acting pump in connection with feeding oil, as it is the pulsation resulting from it which allows one to feel whether the oil is flowing in the tube or not. The simplest form of "feel" indication is to file the tube sufficiently thin in one part to have the stroke of the pump felt through this thin wall, and it is easy to conceive without further explanation how this system can be applied almost anywhere.

No matter how the oil is supplied to the bearings, the point of entrance for the lubricant is worthy of study, and usually it is not in its proper position. It should be remembered that oil has no idea or desire to be accommodating. It is lazy and will take the easiest means possible to escape from fulfilling its mission. It will never work in toward the center of a bearing; it will always work out. It is, therefore, clear that the lubricant should be introduced in the middle of the bearing, but in a reciprocating type of engine or machine this central opening should never supply the oil to the highest point of the shaft or at its lowest point, as the up-and-down stroke of a machine closes the openings, if at the top or bottom, thus preventing the in-flow of oil at the very moment that it is needed. The oil should be introduced, therefore, at a point about midway between the center line of the shaft and its extreme diameter. In a continuous rotating shaft and in one that revolves constantly in the same direction the lubricant should be introduced midway between the center line and the diameter of the shaft, but on the up-coming side, as this is the point above the horizontal center line of the shaft where there is the least pressure. I have many times seen troublesome journals entirely cured by merely changing the oil-supply opening as here suggested.

There seems to be but one danger in the automatic or forced system of lubrication and that is that it works so well that it is apt to be neglected, with the most disastrous results. Yet this can hardly be called the fault of the system. Further, I have heard it objected to because it allows too much leisure to the men on watch. One superintendent on a steamship line assured me that he would rather have his men going around with a squirt can filling oil cups than to be sure that all his bearings were running cool by the use of forced system of lubrication.—W. D. FORBES, in "International Marine Engineering."

New London, Conn.

NOTES ON MOTOR CRAFT.

Considerable interest has been aroused amongst those concerned with internal-combustion engines for ocean-going vessels by the case of the twin-screw motor-driven oil tanker *Sebastian*. This motor ship, which was launched on the 24th April, 1913, was built by the Caledon Shipbuilding & Engineering Company, Ltd., of Dundee, for the *Sebastian* Diesel Motor Boat Company (Messrs. Lane & Macandrew, managing owners), of London, and was the first oil-tank vessel constructed in this country to have two-cycle Diesel oil engines. The following are the leading particulars of the ship:

Length B.P., 310 feet; breadth, molded, 45 feet; depth molded to upper deck, 26 feet 3 inches; height of 'tween decks, 7 feet 6 inches; load draught, 22 feet 1 inch; deadweight on above draught, about 4,600 tons.

The propelling machinery originally fitted in the *Sebastian* was constructed by the Aktiebolaget Diesels Motorer, of Stockholm, and consisted of two sets of marine "Polar" Disel motors of the two-stroke cycle type (single-acting, direct-reversing), driving twin screws. Each motor consisted of six working cylinders having a diameter of 17.72 inches and a stroke of 21.27 inches. On the official trials each set of engines developed 800 B.H.P. at 165 r.p.m. It is important to note that these "Polar" motors were at the time by far the largest the Aktiebolaget Diesels Motorer had turned out.

Some time ago the original engines of the *Sebastian* were replaced by two "Werkspoor" four-cycle Diesel engines, and this event was at once hailed in some quarters as a proof of the superiority of the four-cycle engine over the two-cycle type. Such a judgment was, however, superficial, for the *Sebastian's* "Polar" engines were largely experimental, and it is unfair to compare them with the latest "Werkspoor" practice. The management of the Aktiebolaget Diesels Motorer are anxious that full publicity should be given to their explanations of the failure of the "Polar" engine in this particular instance, and their case is briefly summarised in the following paragraphs.

In developing the marine two-cycle engine there was not the same experience to guide the pioneers as was the case with the four-cycle type, which had been manufactured for stationary purposes for so many years, and, as has already been stated, the "Polar" engines of the *Sebastian* were the largest turned out up to that time. When building them the Stockholm concern were confronted for the first time with the problem of providing the pistons with water cooling. They frankly admit that they did not succeed in making the parts which conducted the water to and from the pistons sufficiently watertight, the result being that considerable quantities of water leaked down to the crankpit, where it mixed with the lubricating oil, and, together with this, entered the bearings of the engines. Thus the actual technical cause of the failure is clear. The steps taken to neutralize the water leakage were inadequate, and, to make matters worse, salt water was, owing to some mistake, used for the piston cooling instead of fresh water, with the result that the bearings were completely ruined in a few hours. The oil with which the engines were lubricated under these conditions consisted chiefly of salt water in which floated black lumps of what had once been lubricating oil.

The Diesel part proper of the machinery only caused very slight troubles. But for the war, the makers of the "Polar" engine claim that they would have been able to demonstrate the suitability and efficiency of the two-cycle principle in the case of the *Sebastian*. As it is, they have designed and tested arrangements which afford practically an absolute tightness at the parts that conduct the cooling water to and from the pistons, and consequently prevent the destruction of the lubricating oil. A much larger installation of two-cycle "Polar" engines has been

fitted on the 6,700-ton oil tanker *Hamlet*, and the results have been entirely satisfactory.

Up to the present over 70 "Polar" engines have been supplied to more than 50 vessels, and a still larger number have been built to the "Polar" design under license. The accumulated experience resulting from the working of these engines has led the Stockholm firm to the conclusion that for medium-sized engines the two-cycle principle is the right one for slow-speed engines for merchant vessels, whereas, up to the present stage of development, the four-cycle type seems to be more adapted for high-speed engines for submarines, etc., than the two-cycle engine.—"The Shipbuilder."

NAVAL VESSELS.

UNITED STATES NAVAL VESSELS UNDER CONSTRUCTION.

DEGREE OF COMPLETION.

No.	Vessel.	Building yard.	Engines.	No. shafts.	Speed, knots.	Percentage machinery completed 1916.		Percentage hull completed Nov. 1, 1916.	
						Oct. 1	Nov. 1	Total.	On ship.
	BATTLESHIPS:								
39	*Arizona*	Navy Yard, N. Y.	Pars. trb. grd. cr.	4	21	98.98	99.27	100.0	100.0
40	*New Mexico*	Navy Yard, N. Y.	Electric	4	21	13.13	14.91	52.0	42.6
41	*Mississippi*	Newport News Co.	Cur. trb. grd. cr.	4	21	51.65	54.72	59.6	52.8
42	*Idaho*	New York S. Co.	Pars. trb. grd. cr.	4	21	58.31	59.99	65.5	62.0
43	*Tennessee*	Navy Yard, N. Y.	Electric	4	21	...	...	1.4	...
44	*California*	Navy Yard, Mare Isl'd	Electric	4	21	...	...	6.1	...
	DESTROYERS:								
66	*Allen*	Bath Iron Works	Pars. trb. grd. cr.	2	30	94.05	95.67	91.4	91.4
67	*Wilkes*	Wm. Cramp & Sons	Pars. trb. grd. cr.	2	29.5	98.09	99.31	95.1	94.9
68	*Shaw*	Navy Yard, Mare Isl'd	Pars. trb. grd. cr.	2	29.5	81.43	85.11	89.0	86.8
69	*Caldwell*	Navy Yard, Mare Isl'd	Curtis trb. gearing	2	32	3.00	3.00	27.8	12.3
70	*Craven*	Navy Yard, Norfolk	Pars. trb. gearing.	2	32	1.09	1.35	9.1	3.6
71	*Gwin*	Seattle Con. & D. D. Co.	Pars. trb. gearing.	2	30	5.41	6.88	10.7	1.4
72	*Conner*	Wm. Cramp & Sons	Pars. trb. grd. cr.	3	30	11.89	16.60	16.1	7.4
73	*Stockton*	Wm. Cramp & Sons	Pars. trb. grd. cr.	3	30	11.91	16.76	16.1	7.3
74	*Manley*	Bath Iron Works	Pars. trb. gearing	2	32	25.53	36.94	35.4	29.5
	FUEL SHIPS:								
14	*Maumee*	Navy Yard, N. Y.	Diesel	2	14	94.24	96.76	100.0	100.0
15	*Cuyama*	Navy Yard, Mare Isl'd	Reciprocating	2	14	78.35	81.75	84.3	83.4
16	.....	Navy Yard, Boston	Reciprocating	2	14	...	...	...	...
	TRANSPORT:								
	Henderson	Navy Yard, Phila.	Reciprocating	2	14	62.50	65.29	86.7	84.6
	SUPPLY SHIP:								
	Bridge	Navy Yard, Boston	Reciprocating	2	14	48.73	56.96	87.3	86.3
21	*Gunboat*	Navy Yard, Charleston	Pars. trb. gearing	1	12	...	...	...	...
1	*Hospital Ship*	Navy Yard, Phila.	Pars. trb. gearing	2	16	...	...	...	...
	TUGS:								
17	*Wando*	Navy Yard, Charleston	Recip. oil fuel	1	11	83.00	90.57	100.00	100.00
18	*Pocahontas*	Navy Yard, Norfolk	Recip. oil fuel	1	11	93.59	96.00	100.00	100.00
	SUBMARINES:								
44	*L-5*	Lake Co., Bridgeport	Diesel-Sulzer	2	14	90.03	93.90	88.2	88.0
45	*L-6*	Lake, Long Beach, Cal.	Diesel-Sulzer	2	14	85.41	86.83	85.3	84.6
46	*L-7*	Lake, Long Beach, Cal.	Diesel-Sulzer	2	14	74.89	75.46	85.0	84.3
47	*M-1*	Elec. Boat Co., Quincy	Diesel-New Lond	2	14	98.20	98.20	99.4	99.4
48	*L-8*	Navy Yard, Portsmouth	Diesel-Sulzer	2	14	41.80	41.93	91 8	90 7
52	*Schley*	Elec. Boat Co., Quincy	Diesel-New Lond	2	20	40.65	46.57	29.3	20.4
53	*N-1*	Elec. Boat Co., Seattle	Diesel-New Lond	2	13	79.95	81.83	73.8	63.5
54	*N-2*	Elec. Boat Co., Seattle	Diesel-New Lond	2	13	78.43	80.09	71.5	60.8
55	*N-3*	Elec. Boat Co., Seattle	Diesel-New Lond	2	13	78.34	79.04	68.9	57.6
56	*N-4*	Lake Co., Bridgeport	Diesel-Sulzer	2	13	37.70	40.70	76.9	71.5
57	*N-5*	Lake Co., Bridgeport	Diesel-Sulzer	2	13	36.80	40.02	73.8	67.9
58	*N-6*	Lake Co., Bridgeport	Diesel-Sulzer	2	13	31.10	38.73	72.4	66.4
59	*N-7*	Lake Co., Bridgeport	Diesel-Sulzer	2	13	29.60	32.70	72.1	66.0
60	.....	Elec. Boat Co., Quincy	Diesel-New Lond	2	20	...	...	5.3	...
61	.....	Elec. Boat Co., Quincy	Diesel-New Lond	2	20	...	...	5.3	...
62	o-1	Navy Yard, Portsmouth	Diesel-New Lond	2	14	11.13	13.54	...	...
63	o-2	Navy Yard, P. S.	Diesel-New Lond	2	14	11.13	13.54	...	...
64	o-3	Elec. Boat Co., Quincy	Diesel-New Lond	2	14	13.51	17.70	23.8	11.8
65	o-4	Elec. Boat Co., Quincy	Diesel-New Lond	2	14	13.51	17.70	23.8	11.8
66	o-5	Elec. Boat Co., Quincy	Diesel-New Lond	2	14	8.77	17.70	23.7	11.7
67	o-6	Elec. Boat Co., Quincy	Diesel-New Lond	2	14	8.77	17 70	23.7	11.7
68	o-7	Elec. Boat Co., Quincy	Diesel-New Lond	2	14	8.77	12.58	23 7	11.7
69	o-8	Elec. Boat Co., Quincy	Diesel-New Lond	2	14	8.77	12.58	23.3	11.3
70	o-9	Elec. Boat Co., Quincy	Diesel-New Lond	2	14	8.77	12.58	23.3	11.3
71	o-10	Elec. Boat Co., Quincy	Diesel-New Lond	2	14	8.77	12.58	23.3	11.3
72	o-11	Lake Co., Bridgeport	Diesel-Sulzer	2	14	5.60	9.50	38.1	31 0
73	o-12	Lake Co., Bridgeport	Diesel-Sulzer	2	14	5.60	6.29	36.9	30.0
74	o-13	Lake Co., Bridgeport	Diesel-Sulzer	2	14	5.60	6.36	35.6	28.5
75	o-14	Cal. S. B. Co., L. B.	Diesel-Sulzer	2	14	4.59	5.63	25.8	16.1
76	o-15	Cal. S. B. Co., L. B.	Diesel-Sulzer	2	14	4.64	5.73	25.0	15.4
77	o-16	Cal. S. B. Co., L. B.	Diesel-Sulzer	2	14	4 68	5.79	24.0	14.4

BOOKS RECEIVED.

RADIODYNAMICS, by B. F. MIESSNER, Associate Member, Institute of Radio Engineers, Expert Radio Aide, U. S. Navy, D. VAN NOSTRAND COMPANY, 25 Park Place, New York. Price, $2.00 net.

A history, methods and apparatus of radiodynamics with numerous illustrations. The author has so treated the subject matter that it is intelligible to the general reader and at the same time does not sacrifice the technical exactitude which makes scientific work of value to the trained engineer.

THE SUBMARINE TORPEDO BOAT, Its Characteristics and Modern Development, by ALLEN HOAR. D. VAN NOSTRAND COMPANY, 25 Park Place, New York. Price, $2.00 net.

A book that presents the submarine in such a manner that it is not only of great interest to the general reader, but also offers to the technical man a source of reference, containing, as it does, information of all types of submarine boats, their inherent characteristics, the problems involved in design and construction, difficulties of operation, present limitations and future possibilities. The illustrations are numerous and good.

ASSOCIATION NOTES.

The regular meeting of the Society for the nomination of officers for the year 1917 was held at the Navy Department, Washington, D. C., on Tuesday, October 3, 1916. The following were nominated:

For *President:*

Captain Harold P. Norton, U. S. Navy.

For *Secretary-Treasurer:*

Lieutenant Commander J. O. Richardson, U. S. Navy.
Lieutenant Commander J. O. Fisher, U. S. Navy.

For *Member of Council:*

Captain T. W. Kinkaid, U. S. Navy.
Naval Constructor Robert Stocker, U. S. Navy.
Lieutenant Commander H. T. Winston, U. S. Navy.
Lieutenant Commander G. W. S. Castle, U. S. Navy.
Lieutenant S. M. Robinson, U. S. Navy.
Lieutenant N. H. Wright, U. S. Navy.
Lieutenant of Engineers Quincy B. Newman, U. S. Coast Guard.

It was voted to place the matter of holding a banquet in 1917 before the membership, and provision for voting on this matter has been made on the ballot for officers.

The meeting for counting ballots cast will be held at the Navy Department, Washington, D. C., on Friday, December 29, 1916, at 4:30 P. M.

The following members and associates have joined the Society since the publication of the last JOURNAL:

MEMBERS.

Alexander, James T., Lieutenant, U. S. N.
Ard, Ligon, Lieutenant, U. S. N.
Short, Edwin T., Ensign, U. S. N.
Smith, Paul Revere, 3d Lieutenant of Engineers, U. S. C. G.

ASSOCIATES.

Arkebauer, Jesse O., Ensign, New York N. M., 215 W. 23d St., New York City.

Browne, George A., Lieutenant, Washington N. M., Box 667, Tacoma, Wash.

Eaton, Guy E., Captain, Minnesota N. M., Lyceum Building, Duluth, Minn.

Evers, Eward A., Captain, Illinois N. R., 1020 Sheridan Road, Wilmette, Ill.

Fuller, R. C., 33d St. and West Avenue, Newport News, Va.

Gladding, Edward P., Lieutenant Commander, Rhode Island N. M., Bristol, R. I.

Gray, Harry, Lieutenant, Texas N. M., care Gray's Engineering Works, Galveston, Tex.

Kahrs, Otto, Dip. Ing., Raadhusgaten 1 and 3, Kristiania, Norway.

Larkin, F. P., care of Newport News Shipbuilding and Dry Dock Co., Newport News, Va.

Lincoln, Preston S., P. O. Box 40, Wareham, Mass.

McIver, Matthew G., 91 32d St., Newport News, Va.

Moore, Robert H., Ensign, Pa. N. M., 175 Upland Terrace, Bala, Pa.

Neal, E. B., Asst. Gen. Mgr. Kinney Mfg. Co., Boston, Mass., 182 Warren Avenue, Wollaston, Mass.

Rogers, E. G., R. D. No. 1, Hampton, Va.

Spinnler, C. E., 82 Wall St., New York City.

W. R. Haynie, associate member, was expelled from membership by order of the Council, October 7, 1916.

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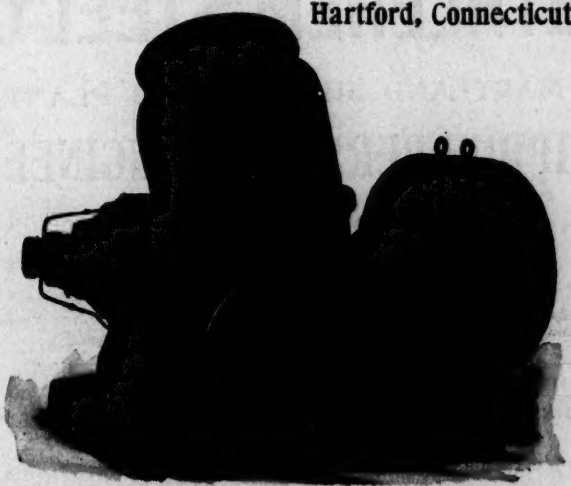

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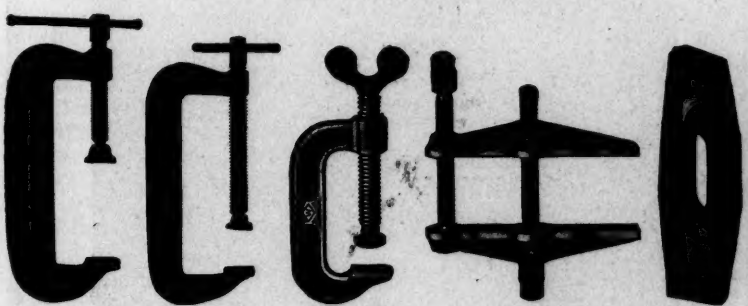

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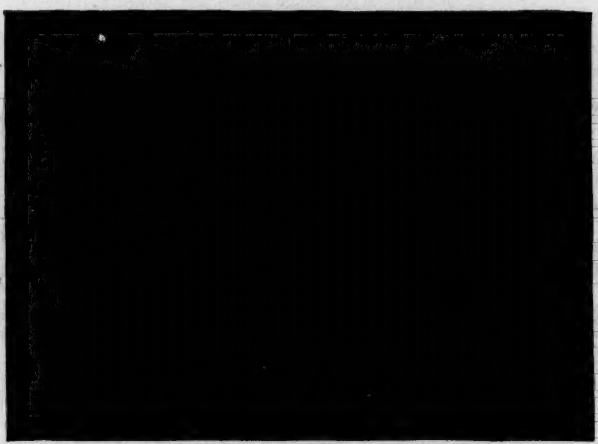

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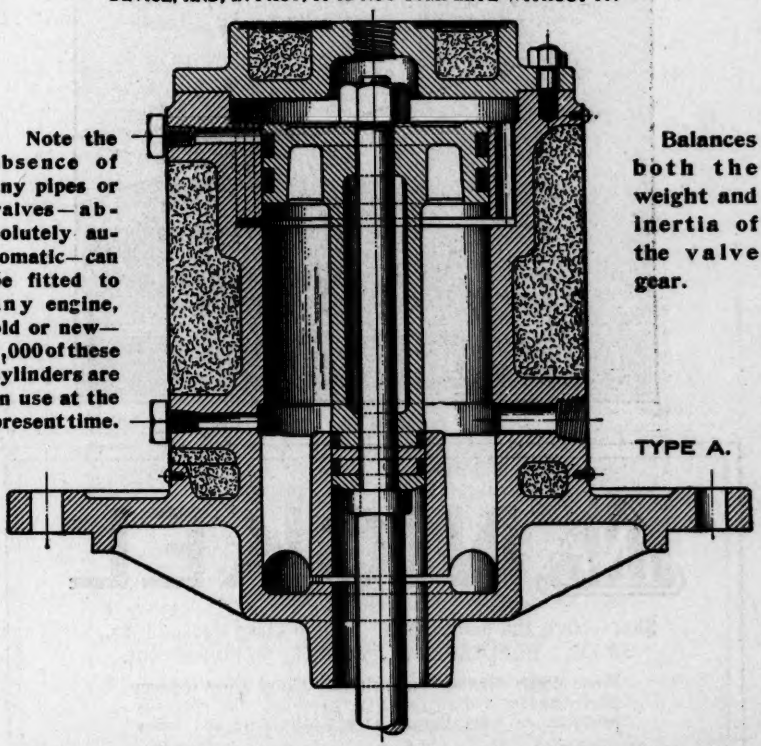

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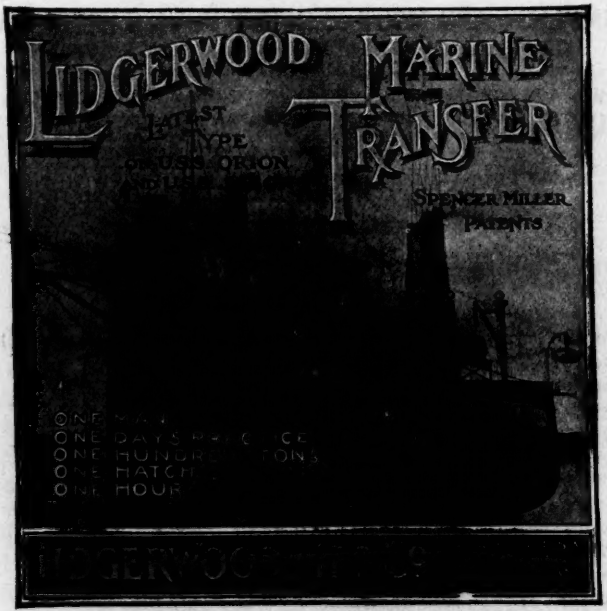

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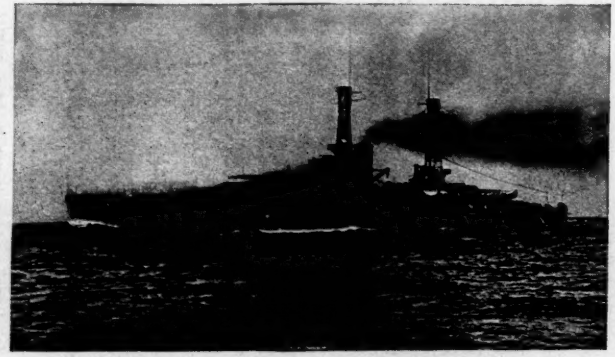

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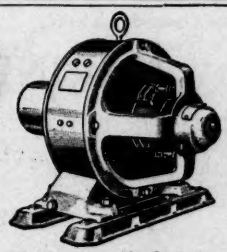

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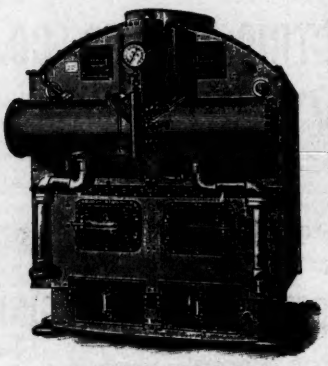

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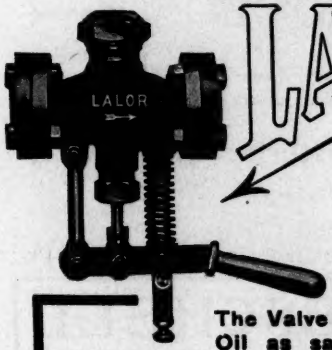

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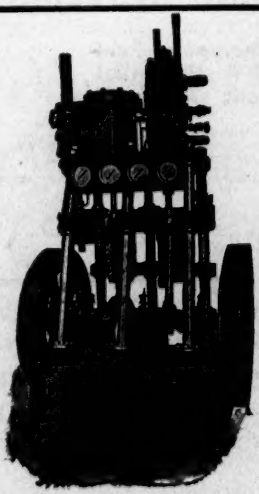

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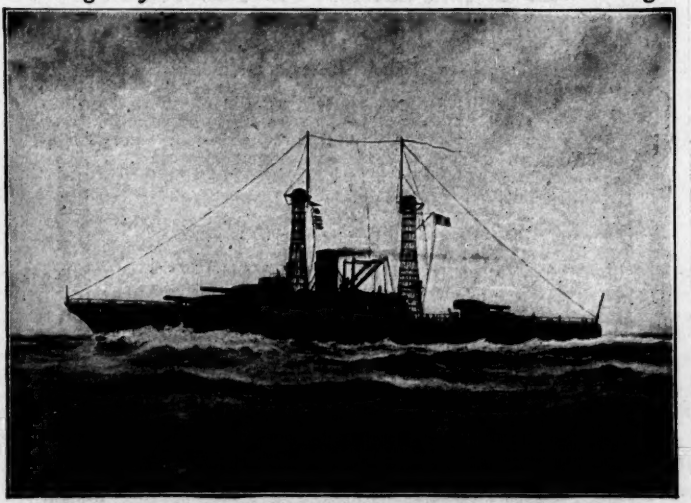

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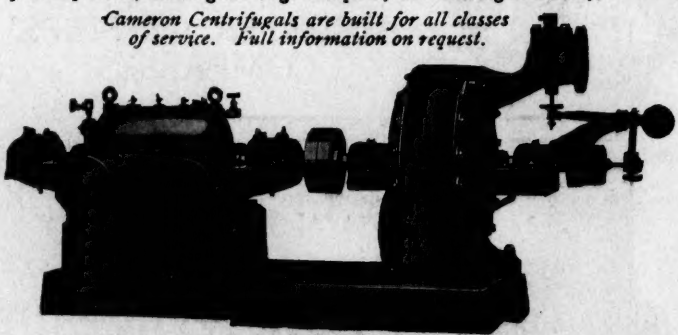

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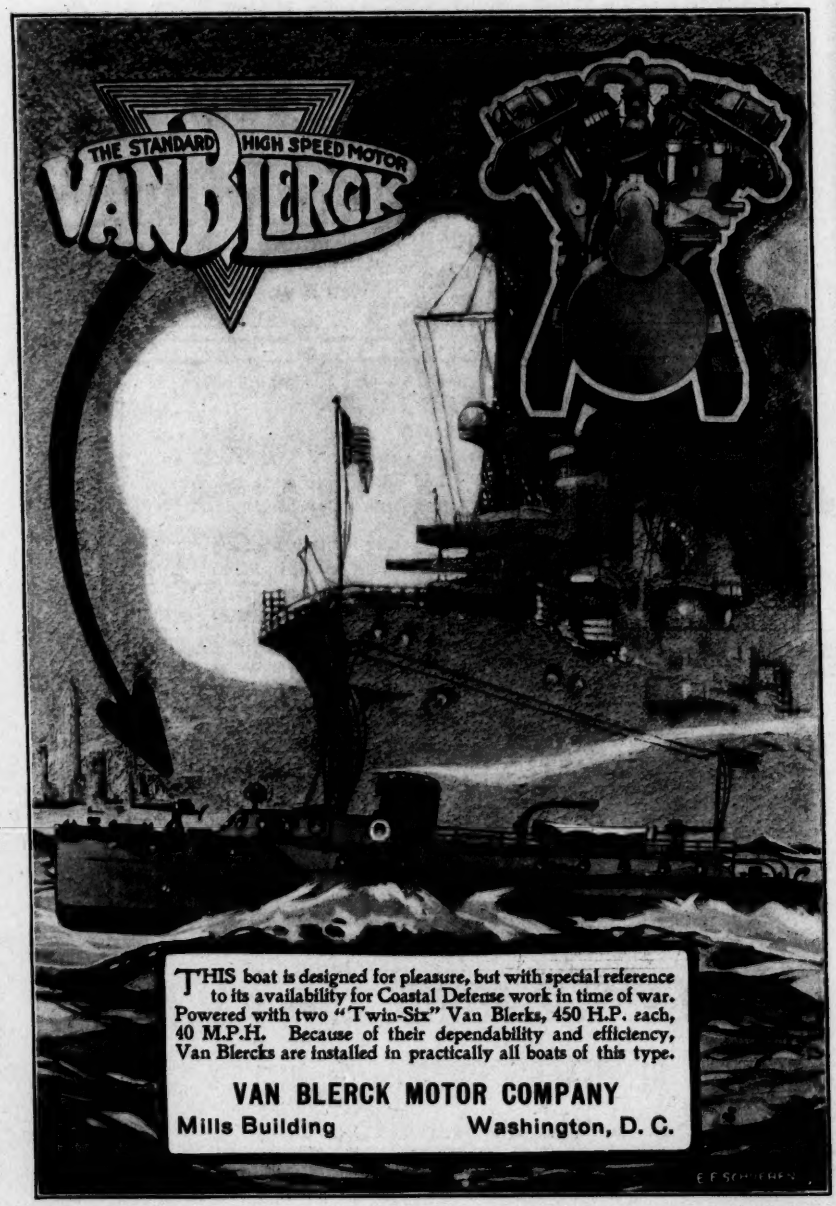
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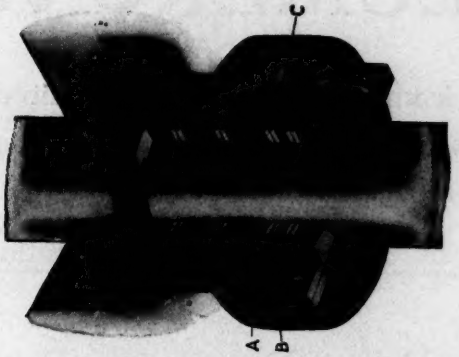

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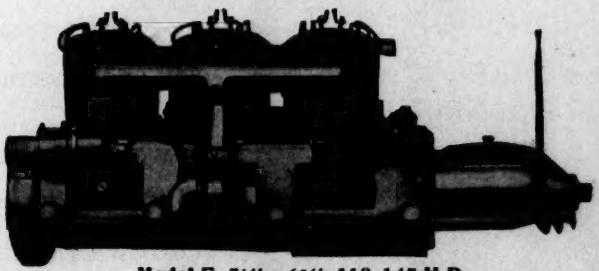

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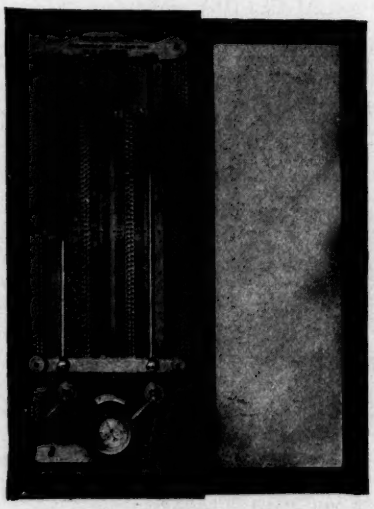

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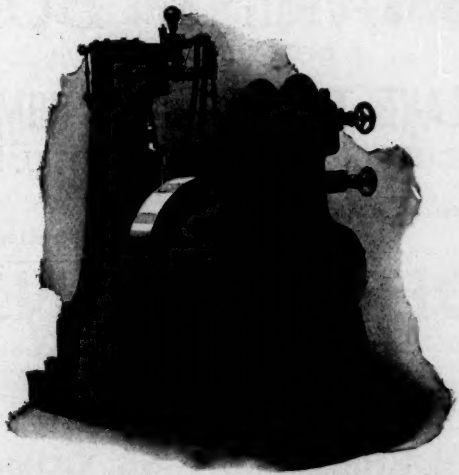

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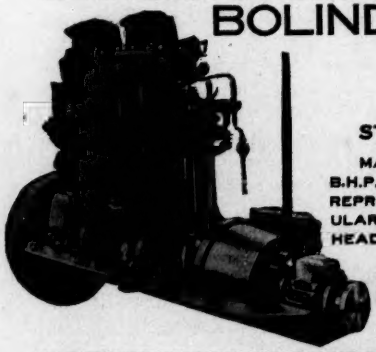

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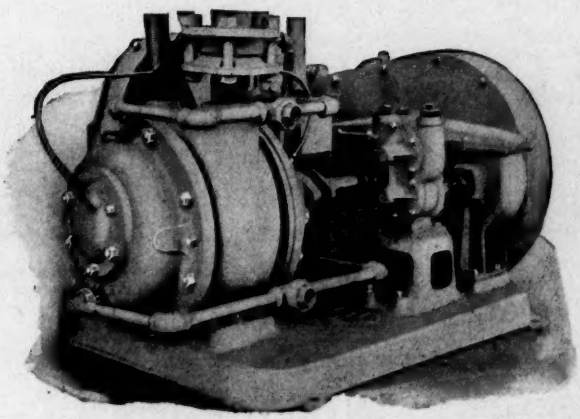

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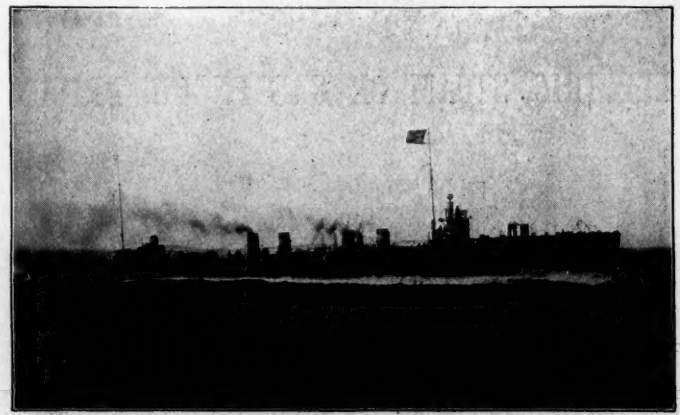

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FOURTEEN DESTROYERS BUILT OR BUILDING FOR THE UNITED STATES NAVY, ALL HAVING SPEEDS OVER THIRTY KNOTS.

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Among the recent installations, U. S. Battleship "Texas" and U. S. Submarine Tender "Fulton."

This system is odorless, non-explosive and efficient.

Catalogue and information on request. Estimates cheerfully made and inquiries solicited.

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Why listen to arguments about the advantages of special forms of tubes and trade names for feed water heaters?

What the Engineers and Owners want are Feed Water Heaters that heat the water to a temperature which is both reasonable and consistent, at the same time the initial cost, together with the cost of maintenance, must be considered.

We have it in the Lovekin Feed Water Heater, as this heater uses the well-known $\frac{5}{8}$-inch condenser tubes without any distortion—simply plain tubes, the same as you use in your condensers. Yet it heats the feed water just as efficiently as any feed water heater can do. Don't be misled by claims made by various makers of feed water heaters, that their particular feed heater will heat water to a higher temperature than another, as all feed water heaters can be made to heat water to the same temperature, if the designer knows his business. Therefore, buy your feed water heaters as you would your coal, viz: from a specification properly drawn up. If you know how much water you want to heat per hour, also the temperature of the water entering the feed water heater, and then the amount of steam you have available for heating the feed water, together with its quality and pressure, we will then advise you as to the proper heater to install for the work. If you don't know the above conditions, let us send our Engineer to help you decide on what is proper.

SCHUTTE & KOERTING COMPANY

12th and Thompson Streets PHILADELPHIA, PA.

NOTICE

In order that all miscellaneous machinery coming under the cognizance of the Bureau of Steam Engineering might come within certain standard requirements, our United States Navy Department has made it a rule to insist on testing, at the Engineering Experiment Station at Annapolis, all apparatus intended to be used on Naval vessels, the expense of said tests being borne by the owner of such apparatus. This arrangement is open alike to the makers of all apparatus intended to be used on Naval vessels.

Having complied with these requirements, we beg to make the following announcement to Shipbuilders and Engineers:

ANNOUNCEMENT

TO SHIPBUILDERS AND ENGINEERS

October 19th, 1916.

We beg to announce with great pleasure that the U. S. Navy Department has recently tested our new design of feed water heater (under the name of The Lovekin Feed Water Heater) at the Engineering Experiment Station at Annapolis, Maryland, and has proven its rated capacity under all conditions. We are now in a position to offer to our customers a feed water heater embodying the most advanced principles in heat transmission at the lowest possible cost. This heater is free from all possible objection and embodies the use of the straight standard ⅝-inch No. 16 B.W.G. condenser tube expanded at both ends (which is so well known among all engineers) arranged with a floating head so as to avoid all possible trouble due to the difference in expansion between the shell and the tubes.

It is the lightest heater ever constructed for a given capacity, it also occupies the least space for a given capacity. We invite your special attention to this heater which we feel assured we can supply you at a cost much less than any feed water heater you can build at your own works for the same output. If you have any doubts as to our ability to do this, we will gladly have our engineering representative call upon you and prove our statement.

Remember there is nothing problematical about our design, as we have been furnished with complete designing data by the U. S. Navy Department, which data was obtained from actual tests made on this apparatus at the Engineering Experiment Station at Annapolis, Maryland.

We respectfully solicit your orders for all feed water heaters for any purpose or for any capacity and are prepared to guarantee all apparatus to meet the requirements of the Bureau of Steam Engineering specifications in every respect.

We are making a specialty of manufacturing these feed water heaters in large quantities, and are therefore prepared to make you attractive prices for all such work.

All of our heaters are fitted with Lovekin Patent Corrugated Spiral Agitators which give a tremendous increase in temperature rise over all other methods for the same length of tube, at the same time we keep within the limit of friction prescribed by the U. S. Navy Department in its standard specifications.

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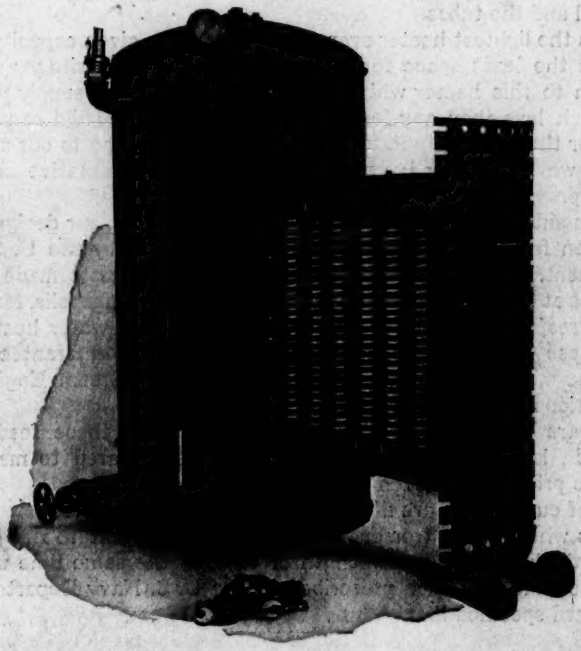

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